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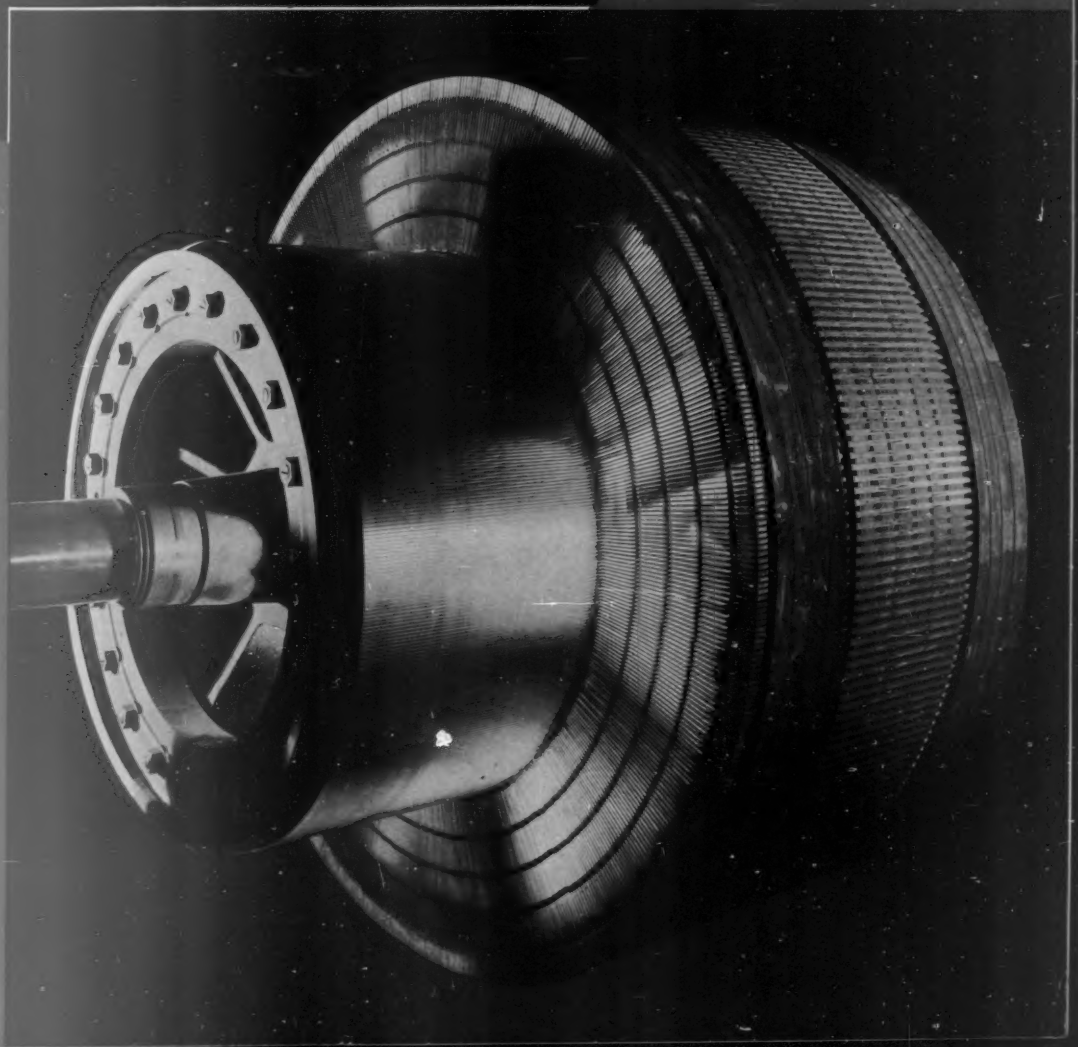
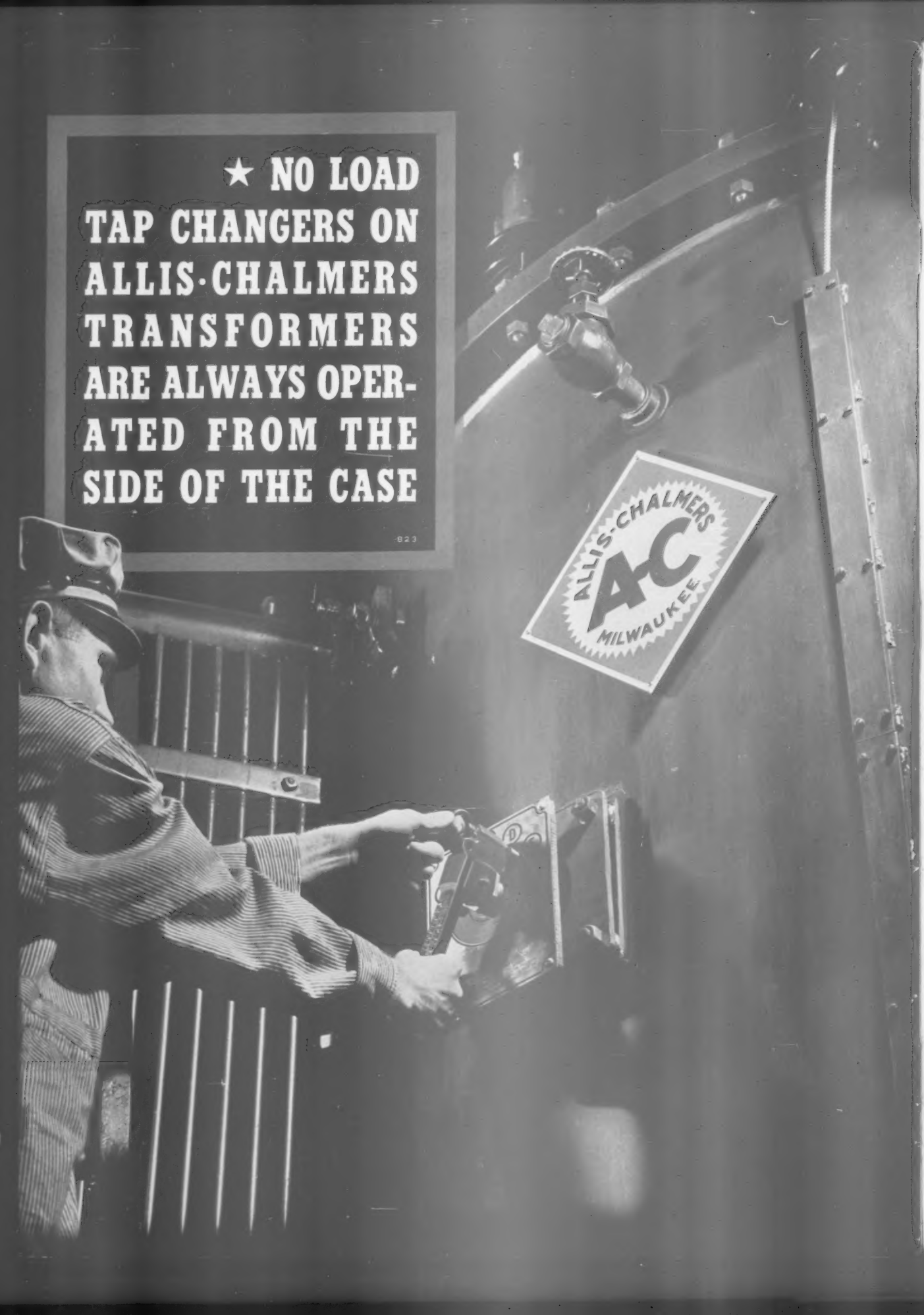
ALLIS-CHALMERS

ELECTRICAL REVIEW

December • 1937

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Vol. II . . . . No. 4

December, 1937

Allis-Chalmers
Electrical Review

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Issued quarterly. Subscription rates: U. S., Mexico and Canada, $2.00 per year; foreign countries, $3.00. Address Allis-Chalmers Electrical Review, Milwaukee, Wisconsin.

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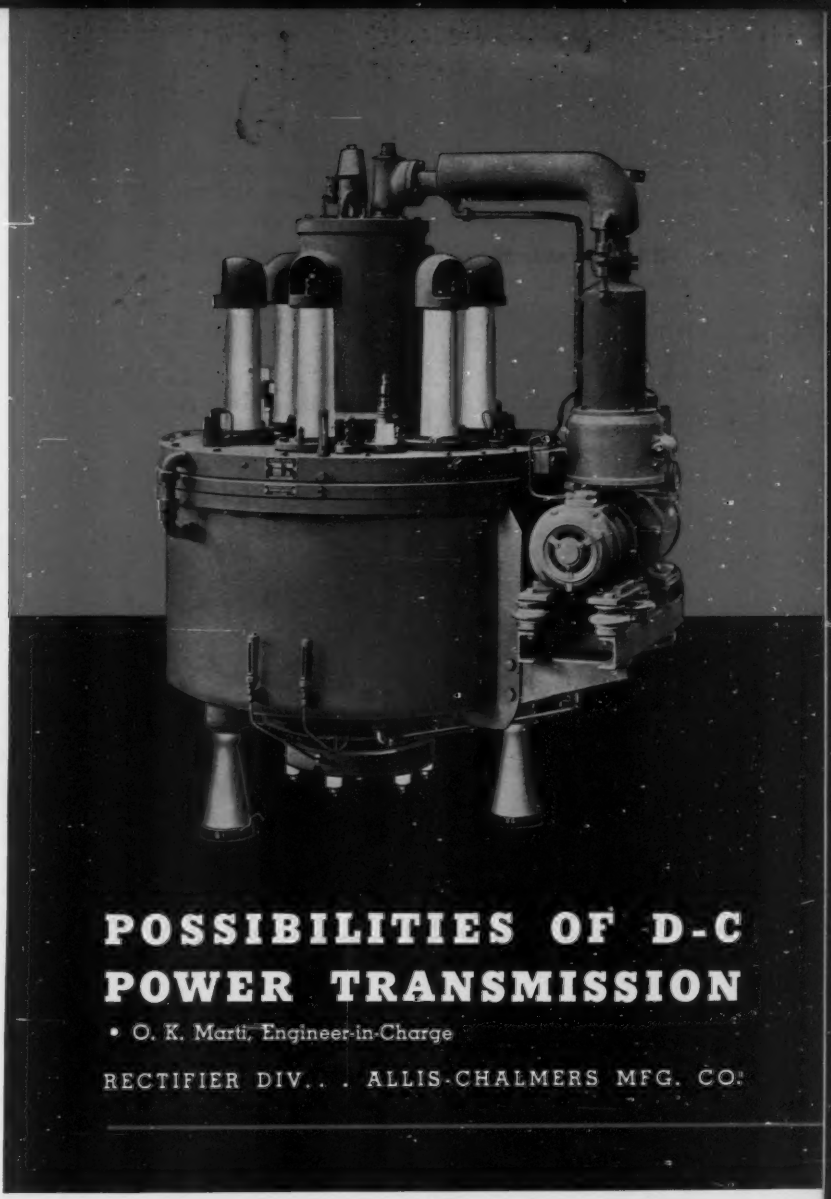

POSSIBILITIES OF D-C POWER TRANSMISSION

• O. K. Marti, Engineer-in-Charge

RECTIFIER DIV. . . ALLIS-CHALMERS MFG. CO.

During the past few years the power stored in coal, oil, and similar deposits has been utilized more and more efficiently. However, in spite of this, it has been found desirable to make use of distant hydro-power resources to a far greater extent than ever before, principally because problems of irrigation and flood control could be solved at the same time. Water power resources are, however, fixed as to location and such locations are often remote from the centers of consumption, necessitating long transmission lines to make the power available at the distribution center. There is also another field for long transmission lines, namely, the interconnection of large and widely separated distribution centers, which are in need of more economical and reliable power transmission.

To do this economically, however, requires a reduction in cost of the line and an improvement of its transmission characteristics. Many comparative cost studies have been made both here and abroad to analyze the economic and service problems, and with them the technical problems incident to the transmission of power from large hydro-power resources to centers of consumption. In most cases it was found that the present way of transmitting such power is far more costly than the hauling of the equivalent in coal to generate the electric power near the center of consumption. The desire to utilize these hydro-power resources can therefore become economically realized only if a new way of transmitting the power can be found, and studies made by a large number of commissions in different countries have again and again come to the conclusion that high-voltage direct current may finally be the means to accomplish this economically.

These studies have also indicated that the transmission of power by high-voltage direct current will reduce and in some cases eliminate difficulties relating to stability, voltage regulation, frequency control, and many of the other problems of a-c transmission, which are causing much concern today when the consumption of electric power is increasing at a high rate. Power surges due to switching, short circuits, ground faults, or the falling out of step of interconnected transmission lines often make it necessary to reduce the maximum power transmitted by a line to a figure below the rating of the system in order to increase system

stability. Generally high-voltage a-c transmission makes it necessary to provide elaborate and special control arrangements for the line itself.

It has already been shown that high-voltage d-c transmission of power is practical. For 30 years such a line operated between Moutiers and Lyon, France. This line transmitted a maximum of 20,000 kw at a d-c voltage of about 125,000 volts and a constant current of 150 amp, over a total distance of 275 miles. Of this distance, 45 miles were in the form of cable; the remaining 230 miles being of overhead construction. The experience gained with this line over a period of 30 years therefore answers practically all questions which may be raised as to the behavior of cables when transmitting d-c power surges and lightning disturbances on overhead lines themselves, and also when overhead lines are operated jointly with cables, the behavior of insulators, corona losses when direct current is transmitted, etc.*

It is well known that the difficulties with the Moutiers-Lyon line were not so much in connection with the line itself and its operation but rather with the generation of direct current at high voltages without an excessive number of rotating machines and commutators; and the only reason why more use was not made of this system is because of the reluctance of electrical manufacturers to increase the rating of their machines due to the serious commutating problems they encountered, as well as the elaborate and lengthy procedure necessary for starting the system. The protection of the line itself against short circuits, lightning, and other operating disturbances was successfully accomplished, and reports indicate that the system had fewer disturbances than any a-c transmission system of comparable magnitude in France.

The above shows that high-voltage d-c power transmission has long been actually in use, and if a three-wire, grounded neutral system is considered, a system of 250 kv can be contemplated without facing any problems which have not already been solved in the Moutiers-Lyon transmission line.

Although, with the exception of the Moutiers-Lyon d-c transmission system in France, a-c power transmission has been universally adopted and used throughout the world, there are many engineers today who are seriously studying and attempting to balance the advantages and disadvantages of a-c transmission of power against d-c transmission and to determine whether the latest progress made in connection with commutators of an electronic and mechanical nature may not overcome the drawback of the above d-c transmission. Particular interest is centered on the possibilities of using electronic power tubes in a d-c transmission system, and so an analysis of the suitability of various electronic vacuum and discharge tubes for high voltage d-c power service is interesting at this point.

Besides the mercury vacuum tube, there are today two quite highly developed types of electric valves which can be used in different circuits for the conversion of alternating current to direct current as well as direct current to alternating current. In order to ascertain which of these three valves is the most suitable, some consideration will now be given to their characteristics.

The first of these three valves — the high vacuum tube — is built today for voltages as high as 500 kv (at one amp) and for currents as high as 200 amp. The disadvantage of this type of valve lies in the fact that its high internal voltage drop results in a low efficiency. The life of these tubes can be considered as about 10,000 hours. High-power tubes of this type have a considerable tendency to flashovers and arc-backs, and the control of the output voltage cannot be accomplished very easily.

The next well-known electric valve is the mercury-vapor-filled hot-cathode tube. It can now be built for voltages of 30 kv and for currents of thousands of amperes. The efficiency of this tube is very high as the voltage drop is only about 20 volts even for very high current outputs. The life of the tube can be considered as about 10,000 hours, although it seems possible that such tubes, when operated at comparatively small currents, as for d-c transmission, may have a much longer life. The tendency to shorts and arc-backs is not great, and the current can be very readily controlled, and even completely interrupted, by means of control grids.

The third type of tube is the mercury-arc rectifier with mercury-pool cathode. The voltage so far obtained with such tubes containing several anodes per tank is up to 60 kv and, as is well known, currents as high as 10,000 amp per tank are successfully handled at low voltages. The life of this tube, especially the tank type, can be expressed in years instead of hours and the tendency to shorts and arc-backs is very slight. Current can be controlled, and even interrupted, by means of electrically energized grids.

In considering other features of these three types of valves, such as the time necessary for making them available for operation, it is found that the mercury-pool tube requires practically no starting time, while the others require up to one-half hour for heating the filaments. Furthermore the filament type valves require an excellent vacuum while the mercury-pool valve does not require a vacuum of such a high degree in order to give proper operation and not have its service life shortened. It is therefore conclusively evident that the mercury arc rectifier, having practically infinite life and already satisfactorily carrying very high currents in commercial operation, appears to be the most promising valve for taking care of the commutation and

* This system is described briefly in an article entitled "D-C Transmission Line in France," which appeared in the Electrical World, May 9, 1936, pp. 1341-1342, and was described in greater detail by R. Thury in Elektrotechnische Zeitschrift, January 23, 1930, pp. 114-122.

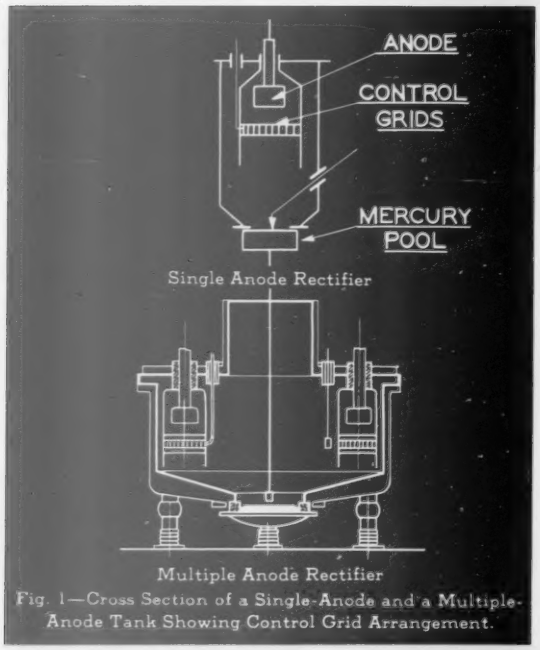

Fig. 1—Cross Section of a Single-Anode and a Multiple-Anode Tank Showing Control Grid Arrangement.

conversion of a-c power to d-c power and d-c power back into a-c power.

The advantages of using such an electric valve for rectification and inversion are to be found not only in obtaining much better commutation than would be possible with mechanical commutators but also in the possibilities of obtaining full control over current flow as well as over voltage by means of electrically energized grids.

• Principle of commutation of power and regulation of voltage by electronic control

There are available various means and methods for controlling tubes and rectifier tanks, but since their effects are the same, the discussion is limited to those types with electrically-energized control grids.

A six-anode tank which may be used as a rectifier or an inverter is shown on page 5. Figure 1 shows a cross section of a single-anode and a multiple-anode tank.

By applying a potential of about 100 to 300 volts (which is negative in relation to the cathode) to the control grids arranged in the arc path (see Fig. 1) near the anodes, it is possible to delay the flow of current to the cathode, that is, the firing of the several anodes, to any desired instant. After the anode has ignited, however, and during the flow of current, the control grid ordinarily used is incapable of influencing the anode current, contrary to the conditions existing in high vacuum valves. Only after the current passes through zero (at the end of the half cycle), does the grid again become operative. By timing the instant of application of the control voltage, it is possible to obtain any desired firing of the current within the positive half-wave of the alternating anode potential. Repeated during successive cycles, this gives a fully continuous regulation of the d-c voltage output, without any appreciable losses. It can easily be seen that by applying a negative blocking potential to the grids, in relation to the cathode, all of the anodes can be blocked from firing. Since each anode of a polyphase rectifier carries current for only a fraction of a cycle, the grids can gain control within a very short time interval, and the current flow can be quickly interrupted.

The oscillogram reproduced in Fig. 2 shows the unusual possibilities of such grid control. A momentary short circuit of about five times normal current was applied to a rectifier while carrying full load. The short was interrupted in the rectifier by the controlling grids in 1.4 cycles (about one cycle after the grid controlling relay closed), and normal service was entirely automatically restored 8 cycles later.

• Principal advantages of electronically-controlled mercury power tubes for d-c transmission

Below are enumerated the main features obtainable by introducing such control grids in a mercury arc rectifier or inverter, showing still further the suitability of these valves and the possibilities they hold for high voltage d-c transmission.

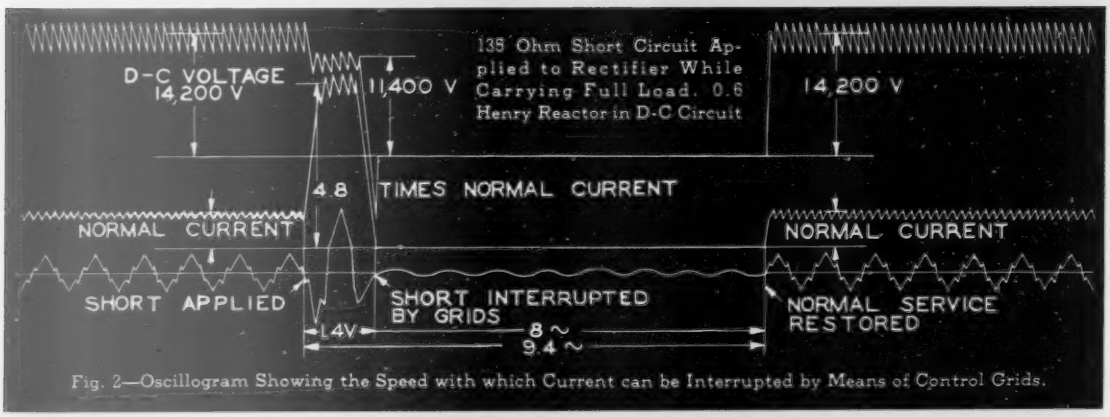

Fig. 2—Oscillogram Showing the Speed with which Current can be Interrupted by Means of Control Grids.

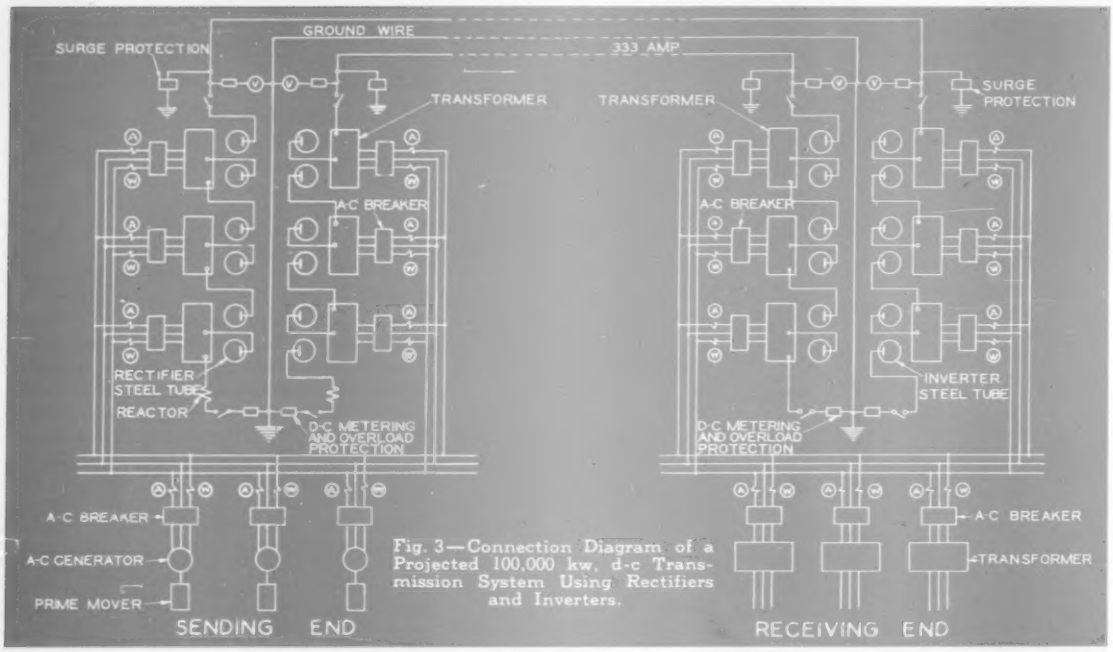

Fig. 3—Connection Diagram of a Projected 100,000 kw, d-c Transmission System Using Rectifiers and Inverters.

The most important features may be classified as follows: extremely fast automatic voltage regulation; voltage control under load without increased losses; and absolutely smooth operation, either automatic or manual (power can be reapplied at low voltage and then automatically increased to its full value very smoothly and at any desired rate, adjustable from about two cycles to two seconds); high-speed protection with electronic interruption of power instead of mechanical interruption; means or possibilities for inversion of reactive energy when cutting off power (this provides quicker interruption and prevents this energy from having to be dissipated in a flashover arc in a protecting device, etc.); automatic means for interrupting and reapplying power in a very short time (1/20 of a second during many tests) when clearing a temporary flashover arc (see oscillogram Fig. 2).

All these control features can be obtained without any great expense, and extremely heavy currents at very high voltage can be controlled by the use of small grid circuit devices involving the switching of only a few milliamperes at low voltage.

Mercury tanks and inverters in which all these features were incorporated and tested have already been built for outputs of 50 kv, 2000 kw, using a tank of medium dimensions, as shown on page 5. Furthermore, several tanks for 25 kv and 1500 kw also were built of this same type and have given very satisfactory operation. Tests have shown that the output voltage can be controlled by means of grids with a very few milliamperes and 200 to 300 volts, and interruption of power can be effected in 1/60 of a second (one cycle) which is much faster than the highest-speed a-c oil circuit breaker in use today for interrupting circuits. In other words, by applying several such valves in series, voltages and currents suitable for transmission of large blocks of power can be obtained.

Electronic rectifiers and inverters with the above-mentioned features are now actually commutating currents and voltages which could not be handled by the commutators of rotating machines. It was, therefore, felt that it would not be amiss to give serious consideration to d-c transmission employing mercury vapor or pool-type rectifier and inverter tubes.* Engineering data are available covering all the component parts of such a system, and operating data of a practical nature obtained in connection with the 125 kv line described above justified the study of the possible use of direct current for transmitting much larger amounts of power over longer distances. Such a system would involve a-c power generated by alternators of standard design at a convenient voltage, stepping up this voltage, converting the current to direct current by mercury arc rectifier tubes, transmitting it by cable or overhead line, then inverting it by similar mercury arc inverter tubes, and stepping it down again to the customary distribution voltage and frequency.

A typical system of d-c transmission, laid out for 300 kv and 100,000 kw, is shown in Fig. 3. This diagram includes both conversion and inversion equipment, and as can be seen one transformer supplies two rectifiers; thus a total of six transformers, each rated at 16,666 kw, will be required. In order to obtain the transmission voltage of 300 kv, 12 tubes — six connected in series between positive and ground and six between negative and ground — would have to be employed. It can be seen that all switching can be done on the a-c side, and the switchgear in the high tension d-c circuits is of the disconnecting type and is provided only for operation without power on the line.

* O. K. Marti, "Rectifier Tests Point to D-C Transmission," Electrical World, July 4, 1936, p. 2054 ff.

• Economic limitations of d-c transmission systems

Considerable differences of opinion exist in regard to the question of the minimum amount of power and the minimum distance for which a d-c system has more advantages than a three-phase, a-c system. One investigator, after careful study, gives the boundary line for these considerations at 100,000 kw, and 100 miles. The correct answer to this question will depend to a large extent on the progress made in the development of the rectifier and inverting units, and preliminary studies have shown that d-c transmission can be used to advantage even when transmitting a relatively small block of power over only 300 miles.*

In fact, it may be that d-c transmission becomes economically advantageous in urban centers with underground cables, when only 15,000 to 50,000 kw are to be transmitted, over distances as short as ten to 25 miles. Such short distances and such small amounts of power have not hitherto been seriously considered as coming within the province of d-c transmission, but the high cost of cables, and particularly the expense of their installation in our large cities, compensates for the cost of the necessary converting and inverting equipment.**

The principal advantages and disadvantages of d-c transmission are summarized below:

1. In connection with the d-c transmission line, there will be no line voltage drop due to inductance and no voltage rise due to capacitance. Therefore, the only voltage drop will be that caused by the ohmic resistance of the line.
2. There will be no phase displacement, due to the above facts, and, therefore, the stability problem existing in a-c lines will not be encountered. Because of the absence of the stability problem, there will be no limitation to the rating of the power line, except by the cross section of the line, which is determined by the current density and the corona effects. For a given system, therefore, this factor and others may contribute considerably to greater economies.
3. The absence of line impedance eliminates the usual compensating condensers along the line and contributes another factor toward economy. Due to the line capacitance, a charging current will occur only during the time of application of the voltage. This time is relatively short and the energy required is, therefore, very small. There is no line charging current necessary during the starting up performance of the transmission line and during operation, except during the transient period.
4. The absence of skin effect makes possible a better utilization of the copper and consequent reduction of the I^2R losses.
5. The corona losses are lower than with alternating current.
6. The permissible voltage of overhead lines with a given amount of insulation can be increased by at least 40 per cent, because of the ratio between the peak and the effective a-c voltages.
7. An even greater increase in the permissible transmission voltage in cable lines can be made — in some cases as much as five times that permissible with alternating current — due to the absence of dielectric losses, etc., present in a-c cable lines.
8. The possibility of exchange of power between independent a-c systems of different frequencies makes expensive frequency-changer sets unnecessary. Moreover, systems of the same frequency need not be synchronized to be connected by means of a d-c transmission line.
9. Particularly valuable in hydro-electric plants operating at heads varying within wide limits (storage plants) is the possibility of supplying a d-c line from an a-c source of variable frequency. In other words, since mercury arc tubes operate equally well at different frequencies, the generator speeds can be adjusted to the most economical values of the prime movers.

It must, of course, be realized that the use of direct current for power transmission would, without question, introduce a number of new problems. Some of these may take a long time before they are solved, but in the meantime they may also be circumvented. One of these will be the fact that it is not, at present, possible without cost to transmit wattless power over a d-c line. However, in most of the projects where d-c transmission would come into consideration, this fact would not be a drawback.

Another problem may be caused by the fact that so far no circuit breakers have been developed for the interruption of direct currents at the voltages which would have to be used for such a line. Switching can, of course, always be accomplished on the a-c side, and the grid-controlled rectifier and inverter (see oscillogram, Fig. 2) may at the same time also partly fulfill the functions of a d-c breaker. Still another problem would arise from the fact that it may be necessary to connect a number of rectifiers and inverters in series, and perhaps also in parallel, to obtain the necessary voltage and sufficient rectifying and inverting capacity.

Since, as indicated above, a much larger amount of power can be transmitted over a given overhead line or cable if direct current is used than if alternating current is used, the economic side of the question is very favorable to d-c transmission, in spite of the fact that rectifying and inverting equipment is necessary, in addition to the usual transformers. Moreover, it will be realized that the longer the transmission line the greater will be the economic advantage, as the converting and inverting equipment will cost the same for a given amount of power, irrespective of the length of the transmission line.

* R. D. Evans, Electrical Engineering, April, 1935, p. 449.

** Herman Halperin, Electrical Engineering, April, 1935, p. 447.

TRANSFORMERS FOR COMBINED VOLTAGE AND PHASE ANGLE CONTROL UNDER LOAD

• L. H. Hill, Engineer-in-Charge
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

Transformers with equipment for changing taps under load have been used extensively, but in almost every case they have been connected so as to give a change of voltage in phase with the line to neutral voltage. In recent years there has been an increasing use of transformers with tap changing under load equipment connected to give phase angle control or to introduce a variable phase displacement in the circuit without disturbing the load. A few transformer units have been installed, which can provide independent adjustment of both voltage and phase angle in the same unit. It is believed that such units will become increasingly popular as the need for phase angle control develops, because, as a rule, in-phase voltage control will be required wherever phase angle control is needed, and usually both must be adjusted independently for maximum flexibility.

The use of phase angle control equipment may be desirable when two circuits of different impedances and carrying variable loads are connected in multiple. Starting at a point A, Fig. 1, where two such circuits are connected together, the variable loads and different impedances in the two circuits AB and AC result in a phase displacement and a voltage difference between the two voltages at B and C, the other ends of the two lines. This voltage difference may be both angular and quantitative. Hence, if the two circuits should be connected together at this point, the difference in voltage due to the phase displacement would cause a circulating current to flow even though the voltages themselves might be equalized in some manner. If the amount of circulating current under this condition should become appreciable, it might be economical to install a combined voltage and phase angle control unit to equalize the voltages and shift the phase position of one of the voltages in order to compensate for the phase angle difference due to load conditions. Likewise, by changing the setting of the voltage and phase angle control units it is possible to change the division of current in the two feeders.

• In-phase voltage control under load

When separate regulating units for in-phase voltage control under load are used, the exciting and series transformers are connected so that the voltage introduced in the circuit by the series transformer is in phase with the line to neutral voltage as indicated in Figs. 2 and 3. Figure 2 shows the vector diagram of the line voltages before the in-phase voltage is added; and Fig. 3 shows the addition of the in-phase voltages AA′, BB′, and CC′ to give the new line voltages A′ B′ C′. It will be noted that the voltages AA′, BB′, and CC′ are in phase with the respective line to neutral voltages AO, BO, and CO.

The actual connections are shown schematically in Fig. 4. The equipment includes an exciting transformer arranged for changing taps under load. The primaries of the three-phase exciting transformer in this case are connected in star, and the secondaries of the exciting transformer each supply the primaries of the series transformer in the same phase.

That the voltage developed in the secondary of the series transformer is in phase with the line to neutral voltage may be readily seen by reference to Fig. 5, which shows all three phases of the exciting transformer primary but shows only the secondary connections required to supply one phase

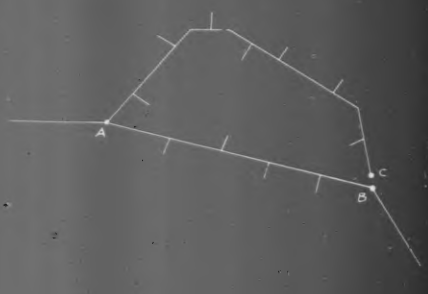

Fig. 1—Branch Circuits of Different Impedances Carrying Variable Loads.

Fig. 2—Vector Diagram —Incoming Circuit.

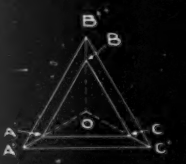

Fig. 3—Resultant Vector Diagram.

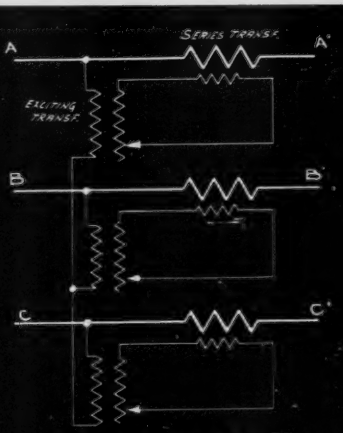

Fig. 4—In-Phase Voltage Control Diagram.

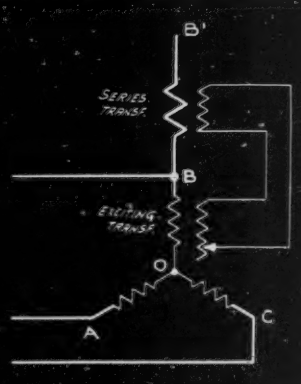

Fig. 5—In-Phase Voltage Control for One Line.

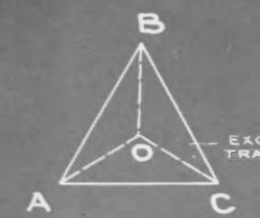

Fig. 6—Vector Diagram —Incoming Circuit.

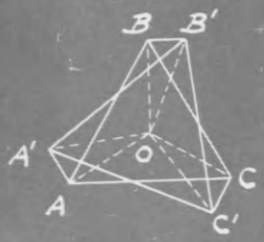

Fig. 7—Resultant Vector Diagram.

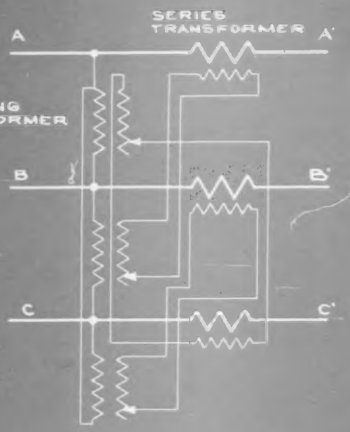

Fig. 8—Phase Angle Control Diagram.

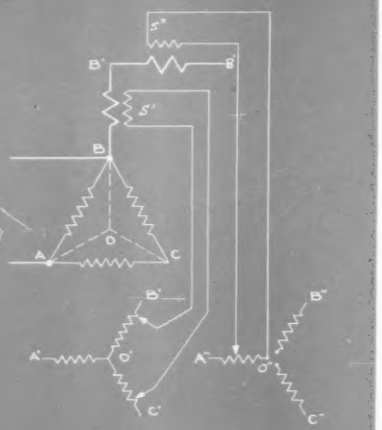

Fig. 11—Combined Voltage and Phase Angle Control for One Line.

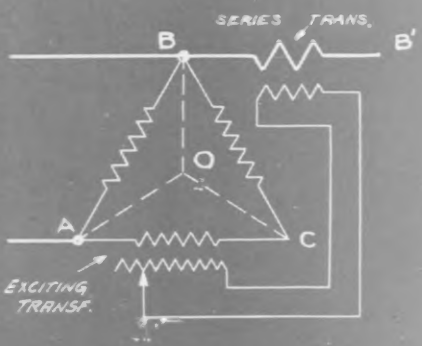

Fig. 9—Variable Phase Shift for One Line.

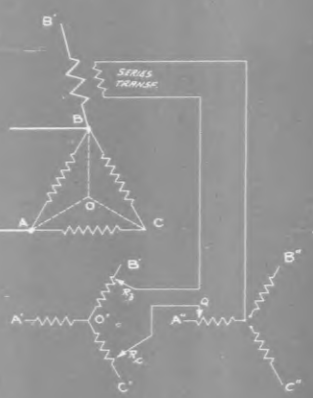

Fig. 12—Combined Voltage and Phase Angle Control for One Line.

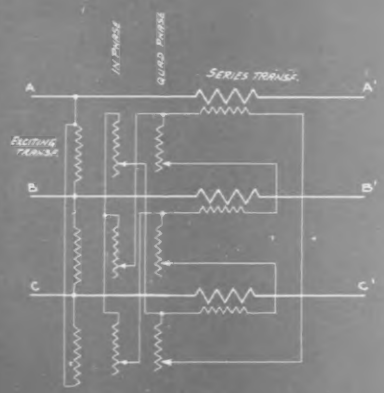

Fig. 10—Combined Voltage and Phase Angle Control.

Fig. 13—Combined Voltage and Phase Control.

of the series transformer — the one in line B. Since the voltage in the secondary of the exciting transformer is in phase with the voltage OB and this voltage is applied to the primary of the series transformer, the secondary voltage BB′ must be in phase with the line to neutral voltage OB.

• Phase angle control under load

Phase angle control under load simply consists of means for impressing a variable voltage in the line circuit which is *not* in phase with the line to neutral voltage. This is done by combining voltages from adjacent phases instead of the same phase. For phase-angle control to be reasonably independent of the in-phase voltage control, the phase shifting is usually done by inserting a voltage in quadrature with the line to neutral voltage. Several combinations are possible, and a typical method is illustrated in Figs. 6, 7, and 8.

Figure 6 shows the vector relationship of the line voltages A, B, and C. To insert a voltage in the line at right angles to the line to neutral voltage requires adding voltages AA′, BB′, and CC′ as shown in Fig. 7. The voltage AA′, however, is in phase with the voltage CB, BB′ is in phase with AC, and CC′ is in phase with BA. Hence to obtain these voltages it is merely necessary to connect the primary of the series transformer across a winding with a voltage in phase with the corresponding line voltage. One arrangement for doing this is to connect the primary of the exciting transformer delta instead of star, as was done in Fig. 4, and cross-connect the secondaries as shown in Fig. 8.

That the voltage developed in the secondary of the series transformer is in quadrature with the line to neutral voltage may be readily seen by reference to Fig. 9, which shows all three phases of the exciting transformer primary, but includes only the secondary connections required to supply one phase of the series transformer — the one in line B. Since the voltage in the secondary of the exciting transformer is in phase with the voltage AC which is in quadrature with the voltage OB and this voltage is applied to the primary of the series transformer, the secondary voltage BB′ of the series transformer must likewise be in quadrature with the line to neutral voltage OB.

• Combined in-phase voltage and phase angle control under load

To obtain independent in-phase voltage control and phase angle control in the same circuit the two separate regulating units of Figs. 4 and 8 may, of course, be connected in the same line, but a considerable reduction in equipment cost can be effected by combining the two into a single unit. Figure 10 illustrates the connections for such an arrangement. The equipment consists of a 3-winding exciting transformer, two separate tap changing under load equipments, and a series transformer in each phase. The primary of the exciting transformer is connected in delta, and the two secondary windings are provided with tap changing under load equipments and interconnected so as to supply voltages to the primary of the series transformer, which may be varied independently to give the desired independent voltage and phase angle control.

The reason for the various connections in Fig. 10 may be seen from the simplified diagram of Fig. 11, which shows the three phases of the exciting transformer and the three sets of secondary windings of the series transformer with only the interconnections of one phase. For simplicity, two separate series transformers are shown in line B — one for the in-phase voltage component and the other for the quadrature voltage component. The neutral of the system is shown at O, and it is evident that to obtain in-phase voltage control in line B, a voltage in phase with the voltage OB should be introduced. Likewise to obtain quadrature voltage control a voltage at right angles to OB should be introduced. It will be noted that the voltage AC is at right angles to OB and the voltage of the secondary winding A″ O″ is also at right angles to OB. Therefore, if the terminals of the winding A″ O″ are connected across the primary of the series transformer S″, the voltage developed in the secondary of this series transformer will be parallel to AC and at right angles to OB, giving perfect quadrature voltage control, assuming the voltage of A″ O″ can be changed under load by the usual methods.

To obtain in-phase voltage control it is desired to impress in the series transformer in line B a voltage in phase with voltage OB. There is no single winding in the secondary of the exciting transformer having a voltage in phase with OB, but it will be noted that the voltage B′ C′ is in phase with BO. Therefore, if connections as shown are led from B′ C′ and applied to the primary of the series transformer S′, a voltage in phase with BO will be obtained in the secondary of S′; and if the position of the connections to the windings O′ B′ and O′ C′ are varied under load by usual methods, perfect in-phase voltage control will be obtained.

For a combined unit the two series transformers S′ and S″ need not be separate but may be combined into a single series transformer with the primary supplied by the same voltages which were connected to their separate and individual primaries. Such an arrangement is shown in Fig. 12. It can be seen that varying the position of the tap lead Q provides independent quadrature voltage control; and, likewise, by varying the position of R_b and R_c toward or away from O′ simultaneously, independent in-phase voltage control can be obtained.

IN PHASE REGULATION					
VOLTS H_1-H_2-H_3 24000 V.(SOURCE)					
VOLTS H_4-H_5-H_6 (LOAD)	% BOOST OR BUCK	POS Nº	A CONN TO TAP Nº	B CONN TO TAP Nº	REV SW ON
BOOST					
28440	18.5	33	8	8	M
28162	17.33	32	7	8	M
27885	16.17	31	7	7	M
27607	15.01	30	6	7	M
27330	13.86	29	6	6	M
27052	12.7	28	5	6	M
26775	11.55	27	5	5	M
26497	10.39	26	4	5	M
26220	9.24	25	4	4	M
25942	8.08	24	3	4	M
25665	6.93	23	3	3	M
25387	5.77	22	2	3	M
25110	4.62	21	2	2	M
24832	3.46	20	1	2	M
24555	2.31	19	1	1	M
24777	1.15	18	0	1	M
24000	0	17	0	0	M

IN PHASE REGULATION					
VOLTS H_1-H_2-H_3 24000 V.(SOURCE)					
VOLTS H_4-H_5-H_6 (LOAD)	% BOOST OR BUCK	POS Nº	A CONN TO TAP Nº	B CONN TO TAP Nº	REV SW ON
BUCK					
24000	0	17	0	0	N
23732	1.15	16	8	0	N
23445	2.31	15	8	8	N
23167	3.46	14	7	8	N
22890	4.62	13	7	7	N
22612	5.77	12	6	7	N
22335	6.93	11	6	6	N
22057	8.08	10	5	6	N
21780	9.24	9	5	5	N
21502	10.39	8	4	5	N
21225	11.55	7	4	4	N
20947	12.7	6	3	4	N
20670	13.86	5	3	3	N
20392	15.01	4	2	3	N
20115	16.17	3	2	2	N
19837	17.33	2	1	2	N
19560	18.50	1	1	1	N

OUT OF PHASE REGULATION					
VOLTS H_1-H_2-H_3 24000V.(SOURCE)					
QUAD VOLTS IN SERIES WITH EACH LINE	PHASE ANGLE	POS Nº	A CONN TO TAP Nº	B CONN TO TAP Nº	REV SW ON
ADVANCE					
6464	25°	33	8	8	M
6060	23°-37'	32	7	8	M
5656	22°-12'	31	7	7	M
5252	20°-45'	30	6	7	M
4848	19°-16'	29	6	6	M
4444	17°-47'	28	5	6	M
4040	16°-15'	27	5	5	M
3636	14°-42'	26	4	5	M
3232	13°-8'	25	4	4	M
2828	11°-32'	24	3	4	M
2424	9°-55'	23	3	3	M
2020	8°-17'	22	2	3	M
1616	6°-39'	21	2	2	M
1212	5°	20	1	2	M
808	3°-20'	19	1	1	M
404	1°-40'	18	0	1	M
0	0	17	0	0	M

OUT OF PHASE REGULATION					
VOLTS H_1-H_2-H_3 24000V.(SOURCE)					
QUAD VOLTS IN SERIES WITH EACH LINE	PHASE ANGLE	POS Nº	A CONN TO TAP Nº	B CONN TO TAP Nº	REV SW ON
RETARD					
0	0	17	0	0	N
404	1°-40'	16	8	0	N
808	3°-20	15	8	8	N
1212	5°	14	7	8	N
1616	6°-39	13	7	7	N
2020	8°-17'	12	6	7	N
2424	9°-55'	11	6	6	N
2828	11°-32'	10	5	6	N
3232	13°-8'	9	5	5	N
3636	14°-42	8	4	5	N
4040	16°-15'	7	4	4	N
4444	17°-47'	6	3	4	N
4848	19°-16'	5	3	3	N
5252	20°-45	4	2	3	N
5656	22°-12'	3	2	2	N
6060	23°-37	2	1	2	N
6464	25°	1	1	1	N

Fig. 14—Sequence of Operations.

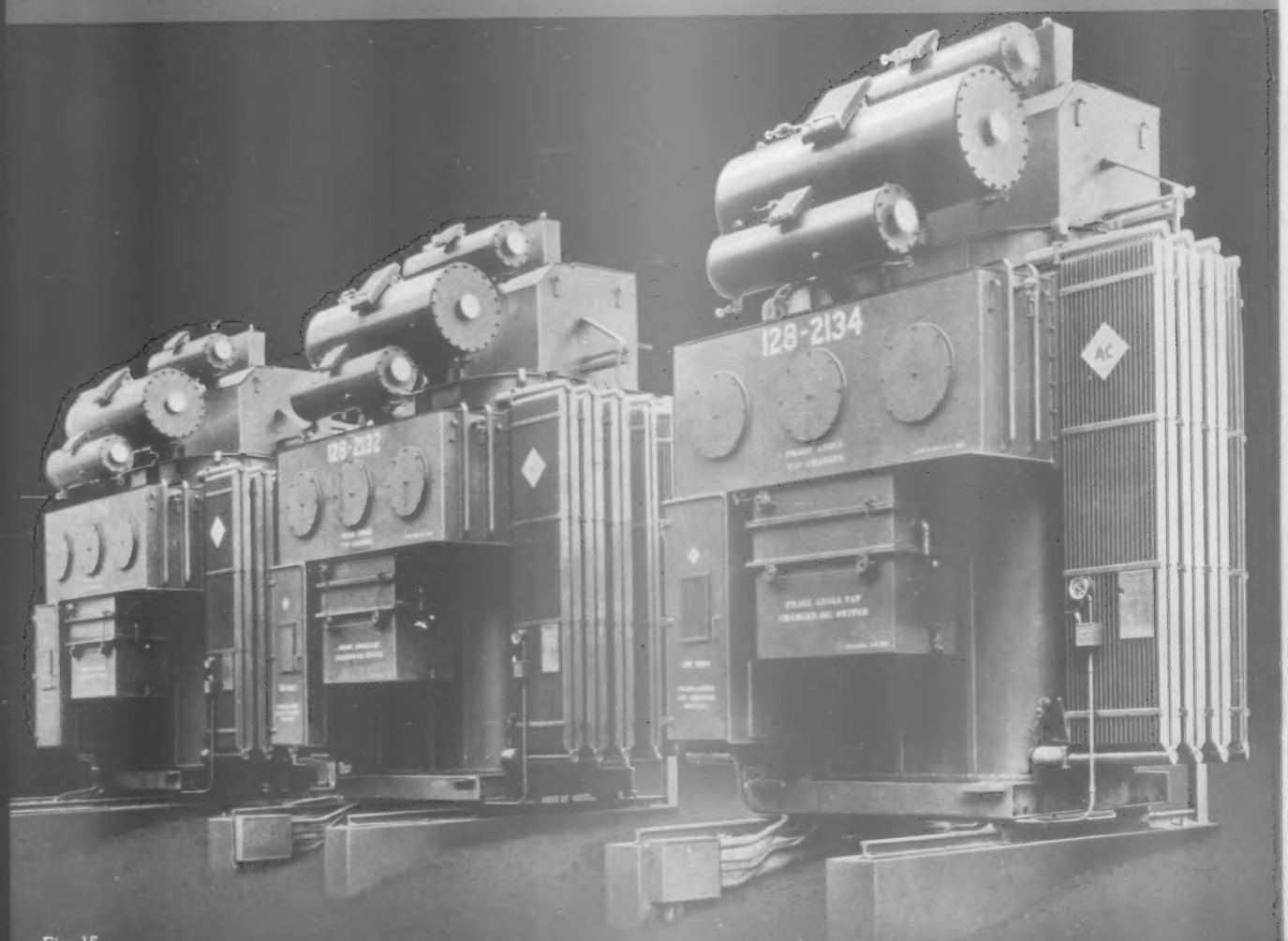

Fig. 15

• Simultaneous voltage and phase angle control

For some applications it is possible to obtain satisfactory results without independent control of the voltage and phase angle by using a unit which increases the phase angle at the same time as it increases the voltage, or vice versa. Here again (see Fig. 13) the principle is illustrated by showing but one phase of the series transformer. It will be noted that the voltage AB is 30 degrees out of phase with the line to neutral voltage OB so the voltage BB′ developed in the series transformer is also 30 degrees out of phase.

• Types of equipment for various functions

The tap changing under load equipment used to obtain phase angle control under load is exactly the same as equipment used for voltage ratio control under load for the same voltage and current conditions. The phase angle control is simply obtained by using different connections in the transformers. Photographs of units illustrating all the principles involved are shown in Figs. 15 and 16. This type of unit regulates 10,400 kva, 3 phase, 24,000 volts to provide independent control under load of in-phase voltage through a plus or minus 10% range in 32 steps, and quadrature voltage to give a plus or minus 25 degree phase shift in 32 steps. The large number of steps is obtained with but eight physical taps in each winding by the use of "half-cycling" operation* and a reversing switch. The in-phase regulation is obtained by the use of the mechanism illustrated on the side of the tank, Fig. 16, whereas the quadrature voltage control is obtained by the mechanism on the opposite side, Fig. 15. The principle of operation is the same in either case except that on account of the greater voltage range required by the quadrature unit, circuit breakers are used to interrupt the current before the dial switches move.

The sequence of operations during tap changes and the complete wiring diagram are given in Fig. 14 and Fig. 17.

The compartment on the cover of the unit illustrated in Fig. 16 contains a three-position disconnecting and grounding switch in circuit with the incoming and outgoing potheads shown at the bottom.

It is evident that transformer units involving combined in-phase and quadrature voltage control under load are entirely feasible. It is, of course, to be understood that phase-angle control may be likewise furnished with transformer units built for straight transformations and not for use as regulating transformers.

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* Electrical Engineering "Step-Voltage Regulators" by L. H. Hill, February, 1935.

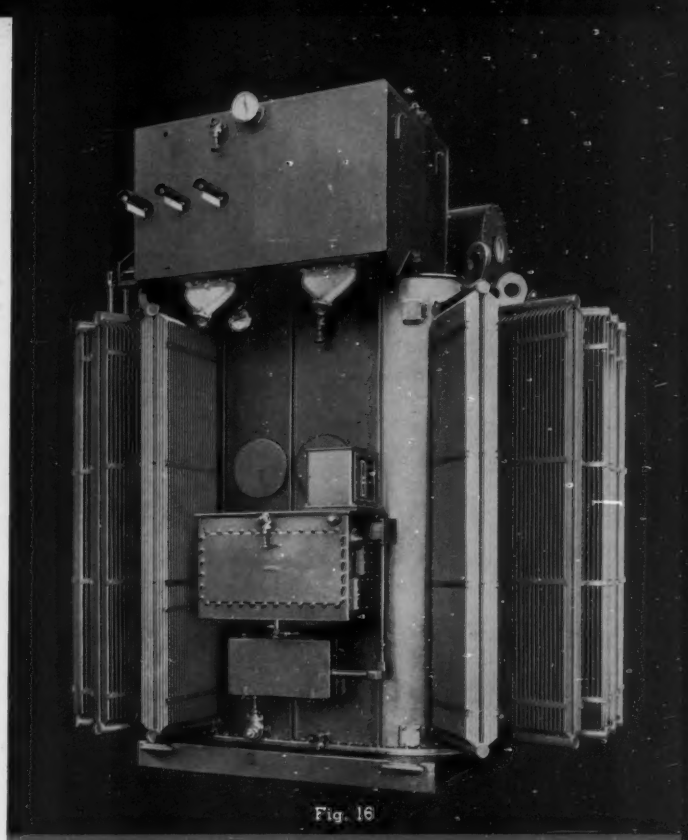

Fig. 16

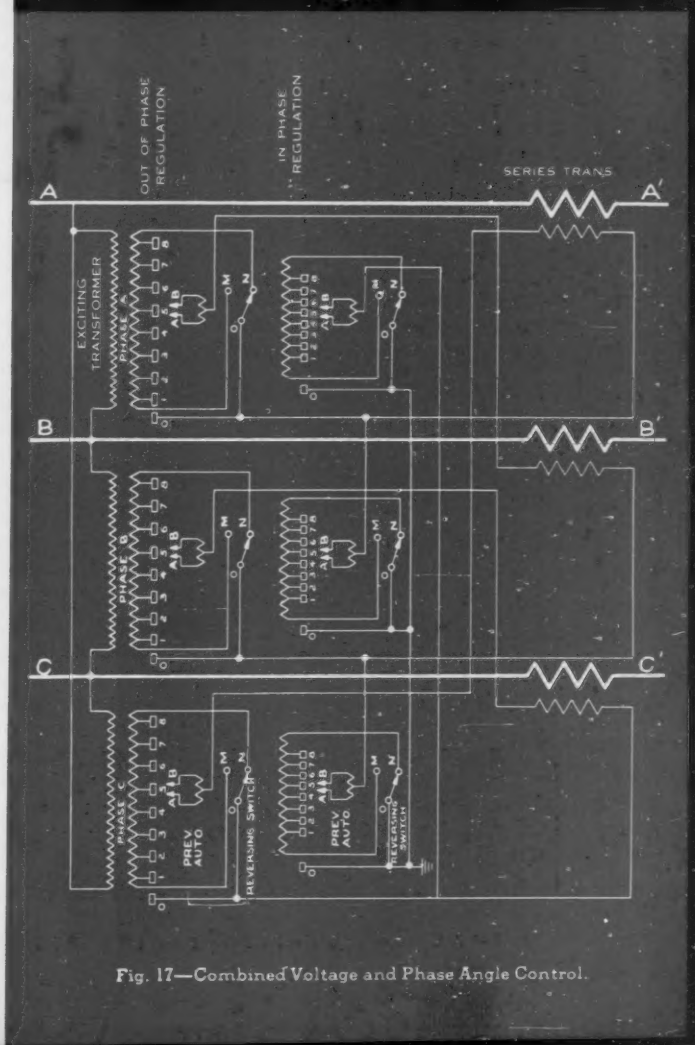

Fig. 17—Combined Voltage and Phase Angle Control.

ENGINEERING FUNDAMENTALS

PRINCIPLE OF RECTIFICATION • ELECTRIC VALVE ACTION

Uni-directional current in a mercury arc rectifier furnishing power to a resistance load as in Fig. 1 is obtained in the load circuit through the rectifying action of the anode in the evacuated chamber. The cathode spot is usually started by means of an auxiliary circuit, not shown in the figure. If the anode is positive with respect to the cathode, the current can flow only from anode to cathode because of the valve action of the anode.

Therefore during the period when anode 1 is positive, a current will flow from anode 1 to the cathode and through the load circuit in the direction indicated by the heavy arrow, and anode 2, being negative with respect to the cathode, will prevent the flow of current from anode 2 to the cathode. During the next half cycle, as soon as anode 2 becomes positive and anode 1 negative, current will flow from anode 2 to the cathode and through the load circuit in the direction indicated by the dotted arrow. It can therefore be seen that the current flowing through the load is always in the same direction in spite of the fact that the power source on the primary side of the transformer is alternating. The two anodes work in rhythm with the impressed alternating current and allow the utilization of both half waves of the impressed voltage. Figure 2 shows the current wave obtained.

The instantaneous values of the two anode voltages have the same magnitude and phase and are 180 degrees displaced. Consequently a series of adjacent half waves are obtained, constituting a direct current with a ripple of the order of 120 cycles. To reduce the ripple it is customary to provide a rectifier with several anodes, the most commonly used circuits including six-anode, 12-anode, and 18-anode rectifiers for transformer connections of double three-phase or six-phase, double six-phase or 12-phase, and triple six-phase respectively.

In a six-phase connection each phase of the secondary winding of the transformer and each anode of the rectifier carries current for only one-sixth of a cycle, as shown in Fig. 3, and the rectifying arc rotates in a circle from anode to anode in synchronism with the frequency of the supply. The rms value of the anode current and the main value of the direct current, considered in Fig. 3, can be determined as follows:

Each anode carries current for one-sixth of an entire cycle, which is equivalent to $\frac{2\pi}{6}$. Then the effective value A of the anode current of a six-phase rectifier in terms of the constant direct current I is

$$A = \sqrt{\left(\frac{1}{2\pi}\right)\left(\frac{2\pi}{6}\right) I^2}$$

$$\text{or } A = \frac{I}{\sqrt{6}}$$

Therefore it is evident that the effective or heating value of the current is not of the order of $\frac{I}{6}$, but $\frac{I}{\sqrt{6}}$, and each of the six phases of the transformer secondary winding must be built for this value of current. Also, each individual phase carries current for only one-sixth of a cycle.

Accordingly it can be seen that the copper of rectifier transformers operated over a comparatively large part of the cycle, as in a two-anode rectifier, is used more than in cases where current is carried for only a small part of a cycle, as in units having a large number of anodes. On the other hand, a higher d-c voltage is obtained through the use of a greater number of anodes, as is evident by comparing Fig. 2 with two anodes and a rectified d-c voltage of .64 E_{max} and Fig. 3 with six anodes and a rectified d-c voltage of .96 E_{max}.

The "utility factor" (utilization of the available transformer capacity) takes into account both the conduction period and the d-c voltage obtained. Figure 4 shows the utility factor for the secondary of a rectifier transformer under various conduction periods and with different numbers of anodes.

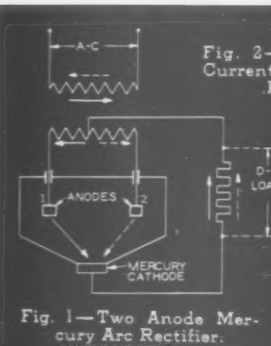

Fig. 1—Two Anode Mercury Arc Rectifier.

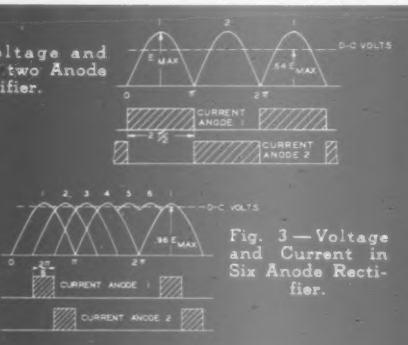

Fig. 2—Voltage and Current in two Anode Rectifier.

Fig. 3—Voltage and Current in Six Anode Rectifier.

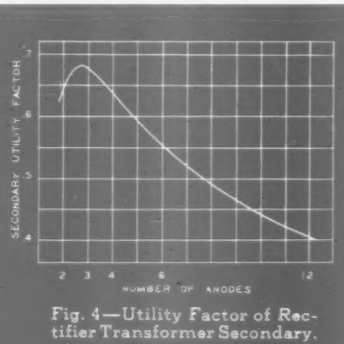

Fig. 4—Utility Factor of Rectifier Transformer Secondary.

CONCERNING TRADE MARKS

• Leo Teplow,
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A trade mark has one basic purpose or function: to *designate the origin* of the goods to which it is applied. It is the signature of the maker or distributor of the goods.

There was no need for trade marks in those ancient times when life was simple and direct. When the shoemaker's customers went to him directly to purchase their shoes, they knew where their shoes came from, and there would have been little use in his applying his peculiar trade mark thereto — unless it was intended as an advertisement to others. Today when a customer enters the shoe department of a large department store, he or she may be met with shoes of dozens of different makes. Modern leather manufacture and ornamentation has reached such a stage of perfection that it is difficult even for an expert to determine the kind and quality of leather used. The average customer, no expert, is in no position to judge by appearance alone. Therefore he is most likely to ask for a certain brand which faith or experience indicates is of good quality. He knows or believes that shoes from the same source have been of good quality or otherwise desirable, and hopes that they may continue to be so. A known trade mark designates the origin of the goods.

This does not necessarily mean the *original* source or manufacturer of the goods. The trade mark in most cases may be the property of the manufacturer who makes and originally distributes the goods; or, in other cases, it may be the property of the distributor who has the goods manufactured by other parties. A manufacturer may have his own trade mark and sell his goods directly or through a large number of retail outlets. On the other hand, a large department store may affix its own trade mark to goods manufactured for the store (and perhaps to the store's specifications) by some manufacturer.

One effect of trade marks seldom appreciated by the trade mark owner is that a trade mark enables the prospective purchaser to avoid shoes of a certain brand. Experience, direct or indirect, may have aroused a prejudice against a certain brand of shoes. Use of a trade mark enables the customer to recognize shoes having that origin so that he may refrain from purchasing shoes of that brand.

Trade marks are so often associated with the concept of good will that trade marks and good will are frequently considered as inseparable as Amos and Andy. It is generally assumed that the value of a trade mark is created by the good will associated with it. Originally this good will was honestly earned by the reliable qualities of the goods which bore the mark. While this is also true in many cases today, yet all too often in recent years we have seen the creation of what may be termed "synthetic good will" — good will based on widespread, repeated advertising.

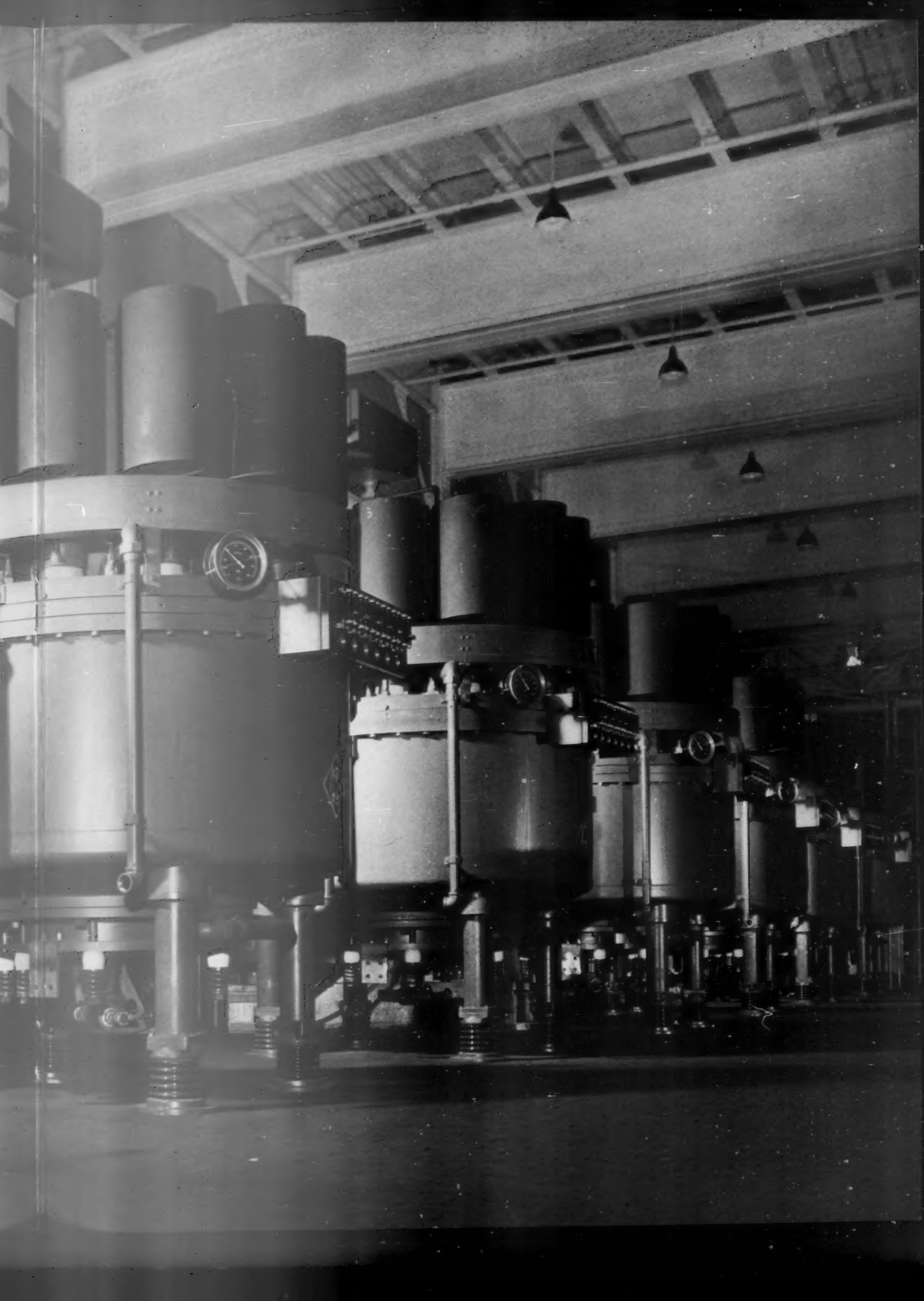
Thousands of non-smokers can name the leading brands of cigarettes, not because they know them by use, but because the trade names have been dinned into their consciousness by way of newspapers, bill boards, radio, etc. It would be difficult to determine how many smokers use their customary brand of cigarette because they prefer it; and how many buy a specific brand of cigarettes because advertising has made it so familiar that it is easiest to ask for. However, whether the good will be earned by quality of product or whether it be synthetic, it is in all cases directly associated with the trade mark and makes it easier to sell a larger quantity of the goods than could be sold if the good will were not existent.

It is the good will associated with a trade mark that makes that trade mark valuable to the proprietor of the trade mark. It is because of the good will associated with a trade mark which is established in its field that newcomers frequently try to adopt a very similar trade mark, in the hope that the purchasing public will fail to differentiate between the two. The fact that such practice constitutes unfair competition and infringement of the existing trade mark does not prevent repeated attempts on the part of hopeful infringers to divert some of the good will associated with an established trade mark to their own benefit.

• Common law rights

Infringement of trade marks is but one sector in the larger field of unfair competition. Unfair competition may consist of any of the various means sometimes used to pass off the goods of one manufacturer as the goods of another. The offense of unfair competition may be committed by copying a competitor's descriptive package so that the goods may be passed off as those of the competitor, in order to benefit by the good will he has established for his product. Any means used to pass off your goods as the goods of some other manufacturer or selling agency would constitute unfair competition. The copying of a competitor's trade mark, or the use of a mark which resembles that of a competitor sufficiently to confuse the purchasing public, constitutes unfair competition through infringement of a trade mark.

The right to a trade mark does not depend on registration of the mark in the United States Patent Office or anywhere else. The right comes into being as soon as a mark has been used on the goods



in commerce (provided the mark does not resemble another's existing mark to the extent of causing confusion in the trade). Registration of the trade mark merely facilitates enforcement of this existing right.

• Registration

While trade marks used in local commerce may be registered in the various states, such registration is not within the scope of this paper. Trade marks used by the owner "in commerce with foreign nations, or among the several States, or with Indian tribes" may be registered in the United States Patent Office. To be a technically good trade mark so that it may be registered under the basic act of February 20, 1905, a trade mark, with certain limited exceptions, must comply with the following requirements:

1. It must not resemble an existing trade mark so closely as to be likely to cause confusion in the trade;

2. It must not comprise immoral or scandalous matter;

3. It must not comprise the flag or coat of arms of the United States or of any state, municipality or foreign nation, etc., or the emblem, flag, etc., of any organization, corporation, etc., incorporated in any state in the United States;

4. It must not be merely the name of an individual or firm, unless written or printed in some particular or distinctive manner;

5. It must not be merely descriptive of the goods; and

6. It must not be merely a geographical term.

Items 2, 3, and 4 are largely self-explanatory, but the other items might be better understood if we resort to a few examples of adjudicated cases.

The resemblance between a proposed mark and an existing trade mark is determined by sound as well as by appearance. Merely misspelling an existing trade mark will not result in a good trade mark. Of recent years the resemblance in sound has been particularly stressed, in recognition of the increased use of radio advertising. For example: "Insta-Matic" was held to be deceptively similar to "DIST-O-MATIC" and therefore not registerable. Similarly "Slices-O-Gold" was held to be deceptively similar to "SUNSET GOLD," and "BECKACITE" is deceptively similar to "BAKELITE," while "PEARLEDENT" is deceptively similar to "PEPSODENT." On the other hand "Thermatic" was held to be not deceptively similar to "OIL-O-MATIC" and "Vapex" was held not deceptively similar to "Vaporub."

It must be understood that similarity of marks is objectionable only if the goods are "of the same descriptive properties." A newcomer may apply a known trade mark which is associated in the public mind with one type of goods to a distinct type of goods. If, for example, "Vulcan" were a known trade mark for locomotives, there would be no objection to another manufacturer's adopting and applying the same mark to goods of different descriptive properties, such as safety pins. It is unlikely that the public would ascribe these goods to the same origin even though the same trade mark were used on both.

Furthermore, a good technical trade mark must not be descriptive of the goods. Everyone selling the same kind of goods is entitled to use descriptive matter in advertising it; hence no one manufacturer would be entitled to exclusive use of some word descriptive of the goods; for example, "DRY-ICE" was held to be descriptive of solid carbon dioxide and therefore was not registerable as a trade mark therefor. "Over Head Door" was held to be merely descriptive of garage doors, and therefore not registerable. On the other hand "Floating Power" was held not to be descriptive of engine mountings. This brings out the point that a mark which is merely *suggestive* of some property of the trade marked product may be a good technical mark; whereas a *descriptive* mark may not be registered.

No trade mark which is merely a geographical term may be registered. This is in fairness to the public. Any product made in a given locality may be described as coming from the locality and no one person may obtain exclusive use of a mark which consists merely of a geographical name. Any hams originating in Virginia may be termed Virginia hams, and all Wisconsin cheese producers may describe their product as Wisconsin cheese. Thus, "Avon" could not be registered for tooth brushes; but "American Lady" was registered for shoes because it was not *merely* geographical.

• Advantages of registration

A trade mark right differs from a patent right. Patent rights do not legally come into existence until a patent is granted; whereas a trade mark can come into existence through adoption and use of the mark in commerce, without regard to registration of the mark.

It may be asked why any one should bother to register a trade mark. Registration is a measure of protection of the trade mark and good will associated with it. Registration of a trade mark in the United States Patent Office constitutes notice to the world that the registrant is the owner of such a trade mark. If it is found that someone is infringing the mark, a statement by the owner that the mark is registered in the United States Patent Office carries great weight. If it is necessary to resort to litigation to enforce the owner's exclusive right to a given trade mark, the court will consider the fact that a mark is registered as prima facie evidence that the mark is valid and is owned by the registrant, making it that much easier to enforce the owner's rights.

Furthermore, if a trade mark is registered in the United States Patent Office, the owner always has the right to bring suit involving such mark in the federal courts, which may in certain cases be a decided advantage. Registration of a trade mark does not give the owner any legal rights which he did not have before; but it makes it much easier to *enforce* his rights.

• Proper use of a trade mark

A trade mark should never be used as a common noun to denote an article of commerce. It should be remembered that a trade mark is used to denote origin of the goods. A "Victrola" is not any gramophone, but only a gramophone produced by a certain company. If the word "Victrola" were permitted to be used to denote any gramophone, and if such use became general and accepted by the public there would be danger of the loss of trade mark rights therein, for then the word would cease being a trade mark and would become a dictionary word which all makers of gramophones as well as the public at large would be free to use. Thus we have the paradox that a trade mark is of most value when it is most widely used, yet, if its use becomes so common that it replaces the name of the article, it may lose all value to the owner.

It is always best to denote that a word is a trade mark by capitalizing it, or by putting it in quotation marks. Better yet, the trade mark may be accompanied with a notation that it is a registered trade mark.

A trade mark should not be used to denote class, grade, style or quality of the goods. The public has a right to describe goods as to their characteristics; and if a trade mark were permitted to become synonymous with some such characteristic the public would have a right to use it, and the owner would lose the exclusive feature of his trade mark. For example, if a distributor of potatoes were to adopt the symbol "67" for a certain grade or size of potatoes; and if such usage became so common that people were to associate "67" with that grade or size of potatoes generally regardless of origin, the mark would then become a *grade* mark; and the owner might lose the exclusive right to it, thereby losing both the trade mark and its associated good will.

A trade mark should be applied to the goods whenever possible; when, from the nature or character of the goods this is not feasible, the mark should be applied to the package or container in which the goods are sold. If it is a registered trade mark, the words "Registered in U. S. Patent Office" or "Reg. U. S. Pat. Off." should appear on or closely adjacent to the mark so that the public may be properly notified of that fact. While the mark need not be affixed to the goods permanently, it should be so applied that it will be apparent to the purchaser while the goods are in ordinary channels of commerce.

The above is but a brief discussion of the subject of trade marks. The value of good trade marks, their wide use, the amount of good will involved and the amount of litigation involving trade marks are sufficiently important to warrant a greater familiarity with the subject than now exists among engineers and executives. Misconceptions concerning trade marks are legion. It is hoped that the above comments may serve to clarify some of the current vague notions regarding trade marks and lead to a greater interest in their proper selection and use.

STEEL MILL SYNCHRONOUS MOTOR GENERATOR SETS

THE OPERATION OF THE SUPERPOSED TURBINE

• J. R. Hageman
STEAM TURBINE DIVISION . . . ALLIS-CHALMERS MFG. CO.

The superposed or top turbine represents a recent development in steam turbines and is finding a steadily increasing field of application. Considering the benefits to station economy which can be derived from the application of higher temperatures and higher pressures, the reason for this trend is easily understood.

The advantages of modernizing an existing power plant through the addition of a superposed turbine are recognized both in the industrial and in the central station fields. The superposition of a high pressure element (boiler and turbine) over a low pressure steam plant can transform an antiquated power plant into a modern one with the least possible expense.

The operation of a top turbine in connection with an existing plant brings about some problems, which should be given due consideration in the plant layout, its design, and the contemplated operating procedure.

• Arrangement of the superposed turbine with regard to an existing installation

A thorough study of the problems involved seems to indicate that the various practical arrangements of superposed turbine application can be grouped under three general classifications. The capacity of the superposed turbine in relation to size of the existing plant, that is, the capacity of existing steam and power producing units, is the determining factor in the grouping. Accordingly, the following discussion is based on arbitrary classification of stations into those with large low pressure systems compared to the high pressure systems, those with relatively small low pressure systems, and those where the low pressure boilers will not be operated after the superposed turbine is put into service.

Although it is conceivable that some installations may require operation of the top and low pressure turbine generators in such a manner that they would not be tied together electrically (supplying 25 and 60 cycle systems), this category will not be considered here. In most top turbine applications under consideration, under construction, or under operation there is an electrical tie-in of the superposed turbine generator with the generators of the low pressure turbine.

Superposed unit operating with large low pressure system. In this classification the capacity of the superposed unit is small with respect to the capacity of the low pressure system, Fig. 1. This arrangement represents the rule during the early stages of a power plant expansion by means of top turbine units. It is expected that a number of low pressure boilers will always be in operation.

Under such conditions it is advisable to load up the top turbine unit to a definite constant output ordinarily limited only by the capacity of the top turbine generator. The low pressure boilers will be operated as usual, that is, to maintain the normal low pressure header pressure. For a given station output the steaming rate of the low pressure boilers will be smaller by an amount depending on the capacity of the top turbine.

The top turbine can be operated like a base load machine. As such its output should be adjustable, but the turbine itself should not be materially influenced by swings of the station load. Load swings should be taken care of by the low pressure turbines and boilers. In order to obtain such operating characteristics, the speed governor of the top turbine should be adjusted to be more sluggish than the speed governors on the low pressure turbines. This type of operation can also be obtained by a load limiting device set conveniently to hold the top turbine at any desired maximum load.

In other words, the superposed turbine is operated like a condensing turbine, its load being regulated by adjustments of the speed governing system. The back pressure regulator, if supplied, is out of service and the low pressure header pressure is maintained by the low pressure boilers.

Superposed unit operating with a small low pressure system. An entirely different operating procedure is necessary when the superposed unit is

connected to a low pressure system of relatively small capacity, Fig. 2. The operating characteristics of both the high and low pressure boilers now become a major factor in determining a suitable operating schedule for the station.

It is quite possible that the high pressure boiler may be able to follow load changes more easily than the low pressure boiler because of its more modern design and more sensitive automatic control equipment. With this condition there is a temptation to hold the low pressure boilers at a constant rate of steaming (base load) and let the automatically operated high pressure boiler follow the swings of the station load. The top turbine would have to be put under control of the back pressure regulator.

The effect of a station load increase would be that the more sensitive speed governors of the low pressure turbines would respond first, tending to take the most of the load increase. But since the low pressure boiler is operating at constant capacity, the pressure in the low pressure header would drop and set the back pressure regulator of the top turbine in action. Falling back pressure would cause an increase of high pressure steam flow to the top turbine, and the high pressure boiler would automatically pick up the steam flow increase. The limitation of this arrangement is that, under the conditions mentioned, the swing of the station load should not exceed the capacity of the high pressure element (boiler and turbine).

From the standpoint of station economy, the above system of operation is detrimental. Maximum economy requires operation of the high pressure element at a more or less constant capacity. This requirement leads to a somewhat different, and certainly more difficult, system of operation.

Instead of operating the low pressure boilers at a constant steaming rate, they are to be so regulated as to maintain an approximately constant steaming rate on the high pressure boilers. If a station load increase occurs, the low pressure turbines will again respond more readily than the high pressure turbine. The increased demand from the low pressure header will cause a drop in pressure, which now will be counteracted in two ways: First, the high pressure element will increase its output due to response of its pressure regulator to a falling pressure on the low pressure header and in part due to speed change. Second, the fireman, determined to maintain pressure on the low pressure header and an approximately constant steaming rate on the high pressure boilers will take appropriate action in adjusting the steaming rate of the low pressure boilers.

The success of this method of operation will greatly depend on the rate of change in the station load. If the rate of change is low and the change is anticipated, it is possible that the low pressure

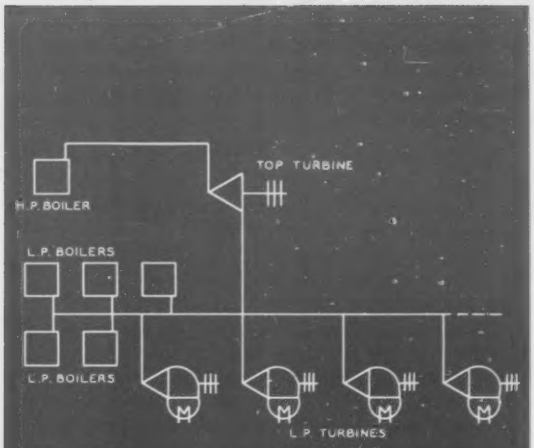


Fig. 1—Superposed Unit with Large L. P. System.

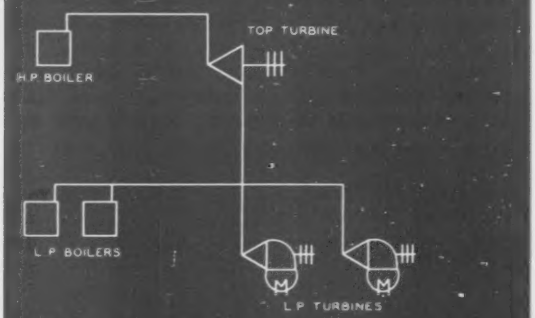


Fig. 2—Superposed Unit with Small L. P. System.

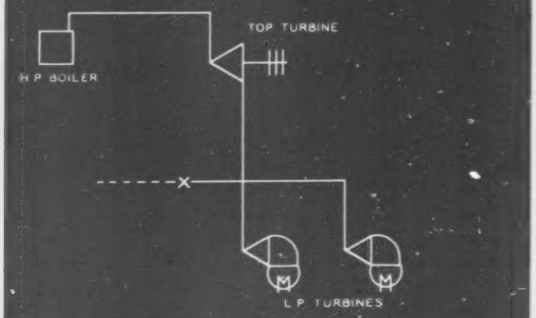


Fig. 3—Superposed Unit with No L. P. Boilers.

boilers can be regulated to keep the low pressure header pressure constant. Under these conditions it would seem immaterial whether the top turbine is under control of the speed governor or the pressure regulator only.

If, however, the rate of change is high and the change is not anticipated, the high pressure element can be made to carry a certain share of the requirements by operating the top turbine under pressure regulator control. A quick change of load will affect the system as already described. The only difference would be that since the low pressure boilers are being regulated for constant pressure on the low pressure header, the output of the high pressure element would be increased only temporarily. For the steady state the output of the high pressure element would be brought back to normal, and the low pressure boilers would operate at increased or reduced capacity, as the case may be. This can be done only if suitable flow meters are installed to show the operators of the low pressure boilers the output of these boilers compared to the total kw.

A word may be said about the transition period. Slow changes in load, irrespective of whether they are in the direction of increase or decrease, will not cause any disturbance. A sudden increase in load will drain the high pressure boiler more if the low pressure boiler is operating for constant output and the top turbine is under pressure regulator control. During the transition period the high pressure element will be loaded up to full capacity. But if the top turbine is under speed control, the increased steam requirements will have to be covered mainly by the low pressure boilers.

A sudden decrease in load would unload the high pressure element in the first case and probably cause the popping of the safety valves on the high pressure boiler. (It is always assumed that the swing is less or equal to the capacity of the high pressure turbine and boiler.) In the second case the burden of regulation rests mainly with the low pressure boilers—a condition that exists in any steam plant that has no top turbine.

Both methods of operation are entirely feasible. When the top turbine is under pressure regulator control and the low pressure boilers are regulated by hand, it should be realized that the pressure range for which the regulator is set should not be too narrow. A small pressure range means large changes in output of the high pressure element, due to imperfect regulation of the low pressure boilers. With very poor regulation (over-regulation) on the low pressure boilers, it is quite possible that the high pressure element might change from full load to motoring with its attendant bad effects.

Superposed unit operating with no low pressure boilers. Here the superposed turbine exhausts into a section of the low pressure header with sufficient low pressure turbine capacity connected, so that the full capacity of the high pressure element can be utilized, Fig. 3. (If there is not enough low pressure turbine capacity connected, the output of the superposed turbine should be limited accordingly by means of a load limiting device.)

For this group also there are two possible systems of operation:

First, the superposed turbine may be put under pressure regulator control and the low pressure turbines placed under speed control. The output of the combination should be regulated by means of the speed changer on the low pressure turbine only. If the combined output is to be increased, it is necessary to increase the steam admission to the low pressure turbine by adjusting the speed changer. The pressure in the low pressure header will then decrease and the back pressure regulator will increase the steam admission to the top turbine. This increased demand from the high pressure boiler will affect its regulating mechanism and increase the boiler output.

Second, the superposed turbine may be placed under speed control and the admission valves on the low pressure turbines opened to an extent corresponding to the maximum steam flow through the top turbine. This combination is identical to a cross-compound arrangement, the load being regulated by the speed changer of the top turbine.

Slow changes in load can readily be taken care of in both cases. Sudden changes in load create no new problems, except that the ability of the arrangement to respond quickly depends entirely on the responsiveness of the high pressure boiler.

It should be noted that the output in the second case has a lower limit, due to the existence of a minimum pressure on the low pressure header at which auxiliaries connected to this header will cease to function properly.

• Governing system of superposed turbine

In principle, the governing system (see Fig. 4) of a superposed turbine consists of a speed responsive device (governor 1), a pressure responsive device (back pressure regulator 2), and a number of links, levers, and relays which translate the impulses into powerful motions controlling the steam admission valves.

The speed governor is of the single spring, fly-ball type. It is driven directly from the turbine shaft at a suitable speed through a worm gear of proper ratio. All moving parts of the governor are sprayed with pressure oil to keep wear and friction to a minimum, thereby assuring maximum sensitivity.

Similar to the arrangement on a standard turbine, the governor stem connects to one side of a

two-arm lever (3). The fulcrum (4) of this lever is adjustable either by hand (hand synchronizer) or by remote control through a small motor (motor synchronizer). The whole arrangement is known under the name of "speed changer." To maintain the high sensitivity of the unloaded governor, the other side of the two-arm lever (5) is not directly connected to the rest of the governor gear but to the pilot of an intermediate relay. This power relay (6) is so constructed that a floating piston actuated by high pressure oil moves practically simultaneously with the inside pilot. The large diameter and the high pressure oil make for a powerful motion of the floating piston. This piston is mechanically connected to a floating lever (7, 8, and 9). The fulcrum (8) of this two-arm lever is provided through suitable linkage from the back pressure regulator (2). During times of operation when the back pressure regulator is rendered inoperative, this fulcrum becomes fixed. The other side of this two-arm lever (9) can move, and its movement is characterized by the fact that its position bears a direct relationship to the position of the steam admission valves and, therefore, to the load on the turbine. Any point on the linkage between this end of the two-arm lever (9) and the valves themselves can be used to measure the load if a suitable scale is provided.

This property is utilized in the next following lever (10) which is mounted on a small torsion shaft (11). The contrivance by means of which the load can be limited is called the load limiting device (12). An adjustable stop in the opening direction of the valves makes it possible to limit the load to a definite figure. One or two additional single arm levers (13 and 14) rigidly attached to the torsion shaft actuate the relay valves (15 and 16) of the main operating pistons (17 and 18) through restoring levers (19 and 20). These relay valves also are pilot operated.

From these operating pistons the steam admission valves are moved through properly dimensioned lever links and cams.

The back pressure regulator (2)—see also Fig. 5—consists of a detecting element (21) and a power element or servomotor (22).

The detecting element is designed to give extreme sensitivity. Friction is eliminated by the use of sylphon bellows and ball bearings. The residual force of the otherwise balanced bellows is counteracted by a light spring (23) acting through a large ratio single-arm lever (24).

Any pressure change at the turbine exhaust influences the detector in such a manner that for any

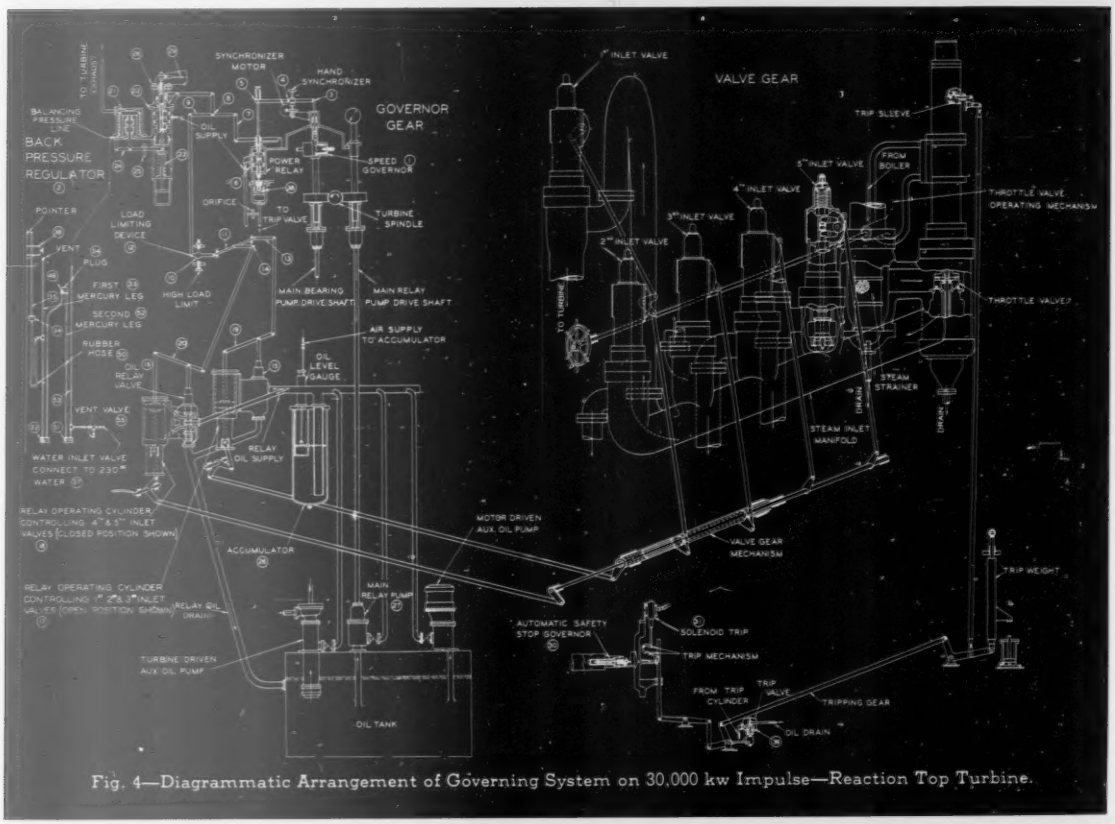


Fig. 4—Diagrammatic Arrangement of Governing System on 30,000 kw Impulse—Reaction Top Turbine.

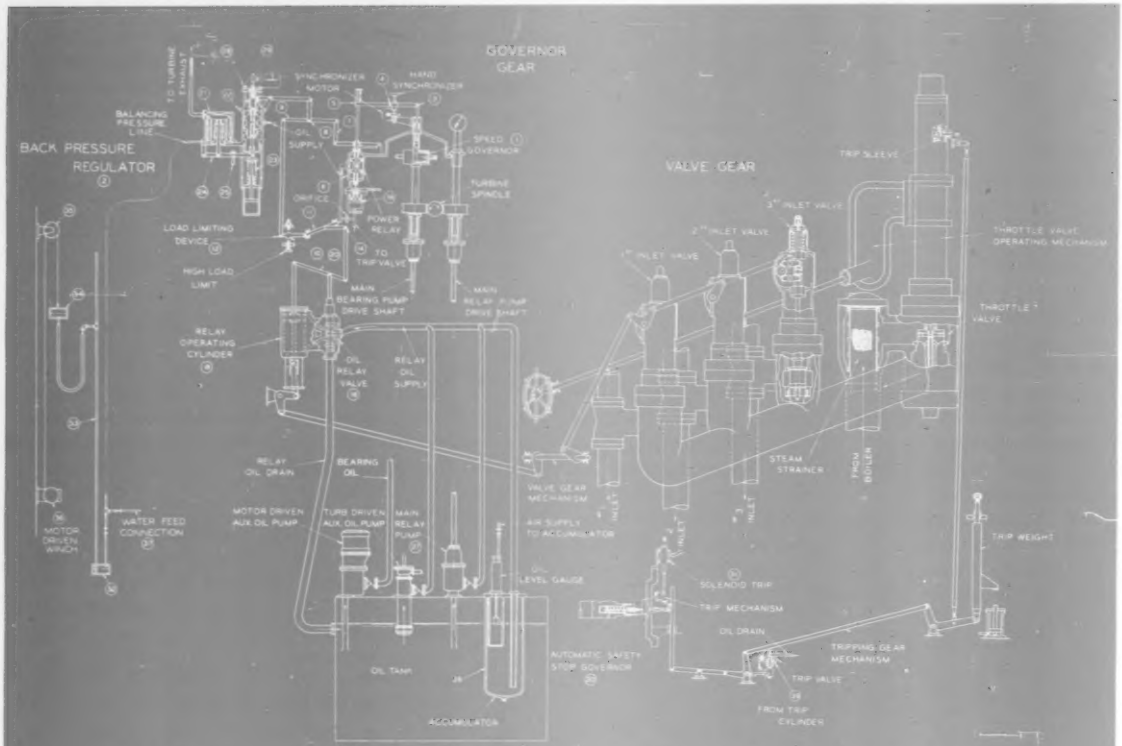


Fig. 4a—Diagrammatic Arrangement of Governing System on 15,000 kw Reaction Top Turbine.

pressure within the range of the regulator there is a corresponding, definite detector stroke. This movement is used to control the power element. The power element (22) consists of a center pilot valve and a floating piston—a duplicate of the one used on the speed governor. By means of the back pressure regulator the position of the steam admission valves is correlated to the steam pressure at the turbine exhaust. If the back pressure decreases by an amount equal to the full pressure range of the regulator, the steam admission valves open fully. In other words, for this pressure change, the turbine output is increased from no load to full load. A change in pressure amounting to only a fraction of the full range loads the turbine a proportionate amount.

Whenever the pressure regulator is cut in, the steam admission valves are under its full control for the normal operating range. The speed governor remains inactive as long as the synchronous speed is maintained but becomes active as soon as the normal speed is exceeded.

Although it would be easy to build this type of regulator for an exceptionally narrow pressure range, too narrow a range may not be desirable. The practical range, as already pointed out, depends on how closely the low pressure boilers can be regulated. The result of a combination of a narrow range regulator with a poorly controlled low pressure boiler will be a widely fluctuating load on the top turbine.

It is now readily seen that irrespective of whether the pressure regulator is in action or not, the speed governor is always connected and will influence the position of the valves as soon as there is a deviation from normal speed.

The operating pistons (17 and 18) are of sufficient size to positively control the steam admission valves in both the opening and closing directions.

For reasons mentioned under Emergency Operation, it is seen that it is of vital importance on a top turbine that the steam admission valves can be moved over their full stroke in a fraction of a second. The power requirements can be taken care of by properly dimensioning the pistons, provided there is a sufficient supply of high pressure oil.

However, a pump of a capacity to meet the momentary oil requirements at the pistons would have tremendous physical dimensions and would be highly uneconomical for normal operation.

This problem is solved by the introduction of an accumulator (26), which is an air- and oil-tight tank of suitable capacity, directly connected to the high pressure oil system.

The oil level is set by admitting compressed air at the top of the tank. The pressure of the oil is balanced by the air cushion.

This accumulator is capable of discharging oil at an exceedingly high rate if a sudden demand arises, and in this way assists the main oil pump (27) during periods of quick regulation.

• Method of putting superposed turbine in operation

On a straight condensing turbine the procedure to be followed in putting it into service depends on the condition of the turbine when starting up. If the turbine is cold, one method is followed; and if the turbine is to be started up after a short shutdown, a somewhat different method is followed. This also applies to a top turbine, except that the procedures are different.

Starting from a cold condition. Since, in most cases, there are two sources of steam available, steam from the high pressure boiler and steam from the low pressure boiler, the question arises as to which source should be used for warming purposes. There are two things that must be considered: first, a warming process is carried out more successfully with steam at moderate temperatures; and, second, the true field of application for the top turbine is at high pressures and temperatures.

If it is possible to control the superheat on the high pressure boiler in starting it, it seems feasible to start the boiler and turbine together. However, if low pressure steam is available from the low pressure header, it is proposed to start the warming process by admitting low pressure steam to the exhaust of the top turbine. The steam flow is controlled by a small, hand-operated valve which is located in a by-pass around the exhaust check valve.

The steam flows through the turbine in a direction opposite to the normal flow and is taken out through the high pressure gland leak-offs to an open heater.

During this warming process all drains are fully open and the spindle is rotated by a turning gear. A small amount of water is admitted to the water-sealed glands in order to condense any steam which might leak past the baffles of the water-sealed glands.

After the turbine is thoroughly heated to the exhaust temperature, the by-pass around the exhaust check valve is closed and steam is admitted from the high pressure boiler. The second step will bring the temperature of the turbine well above normal exhaust steam temperature. After the proper period of preheating in the manner described, the turbine is ready for operation.

Starting from a warm condition. During a shut-down of short duration the spindle turning gear should be kept in operation to prevent the distortion of the spindle. Because of the large heat capacity of the cylinder and spindle and a liberal amount of insulation, the temperature of the turbine will drop very slowly. It is expected that even after a shut-down of 24 hours the turbine will be in a condition to be preheated and operated with high temperature steam.

To put the turbine on the line it is recommended that the pressure regulator (2) be entirely cut out by means of excenter (25) or the locking device (28), and the top turbine may then be synchronized like a condensing turbine by means of the synchronizer (4).

If a top turbine in conjunction with a low pressure turbine has to be synchronized with an existing system (no low pressure boiler capacity available), the two turbo-generators have to be brought up like a cross-compound unit. Both generators are excited at standstill before steam is admitted to the high pressure unit. After full speed is reached, the units are synchronized.

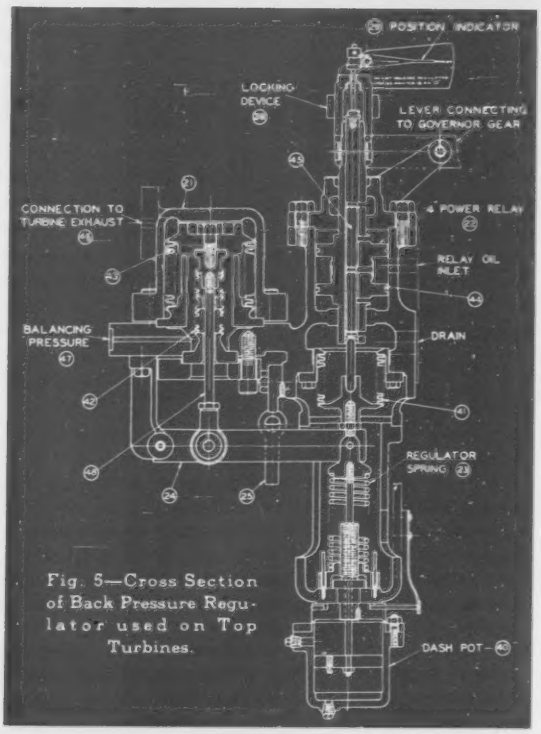


Fig. 5—Cross Section of Back Pressure Regulator used on Top Turbines.

• Normal operation

As mentioned before, there are two possible ways the top turbine must operate—under speed control or under back pressure control.

Speed control. When operating under speed control this type of turbine will act just like a condensing turbine, that is, the load is adjusted by means of the speed changer or synchronizer (4), and provision is made to accomplish this either by hand at the turbine or through the synchronizer motor from a remote point. The steam admission valves are under control of the speed governor (1). The pressure regulator (2) is made inoperative and the exhaust pressure changes with the load unless this pressure is maintained by proper regulation of low pressure boilers which feed into the low pressure header system.

Back pressure regulator control. It was previously stated that the back pressure regulator controls the steam admission valves over their full stroke when the exhaust pressure changes by an amount equal to the range of the regulator. The output of the top turbine and the pressure on the low pressure header has a definite relationship in this arrangement.

Changing from speed control to pressure regulator control and vice versa. The fluctuating load conditions of a power station during the day may make it necessary to change the arrangement of the power producing units either for reasons of economy or convenience of operation.

Assuming that the top turbine was operating under pressure regulator control and is to be changed over to speed control, the change is extremely simple, as it is only necessary to block the pressure regulator in the existing position. This is done by clamping the piston of the power element of the regulator (28). Since the speed governor and the speed changer are in operation at all times, the load can be adjusted by means of the speed changer. It should be noted that as soon as the regulator is blocked the correlation of load and back pressure disappears and both can assume arbitrary values.

When control from the pressure regulator is desired, a different procedure is necessary.

In order to get a better understanding of the situation, it may be well to cite an analogy. Suppose two distinct net works are supplied by two groups of generating units in the same station. The two groups of units may be tied together only through a common bus. It is simple enough to separate the two systems by opening the bus tie; but if it is desired to close the tie again, it becomes necessary to synchronize the two systems.

In changing over from speed control to pressure regulator control, a similar situation arises, that is, the need to "synchronize" the pressure.

The condition of the speed changer and the pressure regulator before the change to speed control can be explained as follows: The top turbine was carrying a certain load, say 15,000 kw (half load). Because the turbine was controlled entirely by the pressure regulator (2), the speed changer (4) was in its original position since the top turbine was put on the line. Suppose the normal no-load back pressure was 220 lb per sq in. and the pressure range of the regulator, 10 lb. Then at 15,000 kw the pressure would have been 215 lb per sq in., and the regulator would have been in mid-position when it was locked.

Since the change to speed control, the exhaust pressure may have changed to an arbitrary value of, say, 220 lb per sq in. The load may have been changed to the maximum output of 30,000 kw. Under these conditions it would be desirable to go back to pressure regulator control.

First, it can be seen that the pressure at the exhaust has risen to 220 lb per sq in., whereas it should be 210 lb according to the load carried at present. Second, it will be observed that the regulator still is locked in a position corresponding to 15,000 kw. Third, the speed changer is now in a position corresponding to 30,000 kw based on mid-position on the pressure regulator.

In "synchronizing" the superposed turbines, all incompatibilities must be removed. The steps necessary in this particular case are: First, lower the pressure on the low pressure header. Since it is necessary to pass the pressure (215 lb) at which the regulator was cut out, the pressure regulator should be released when the pointer (29) on it reads zero. Lowering the pressure further would cause the regulator to move and tend to load the unit more. The load, however, should be kept constant by adjusting the speed changer (4) in the proper direction. This adjusting of the pressure at constant load is continued until the pressure is reached that corresponds to the load carried, which in this case is 210 lb per sq in. At this point the pressure regulator is in the position that corresponds to full load, and the speed changer is back in its original position.

Generally speaking, the low pressure header pressure is brought back to a value corresponding to the load when the regulator was cut out; then the regulator is released and the pressure adjusted to a value corresponding to the present load. During the adjustment the load is kept constant by moving the speed changer.

• Emergency operation

Conditions may arise in the operation of the superposed turbine which may be more or less unusual and are, therefore, termed emergency conditions.

The top turbine may be under pressure regulator control and furnishing steam into the low pressure header, together with some low pressure boilers. Through inability to maintain the pressure on the low pressure boilers, the top turbine will pick up load. If the header pressure drops below the pressure limit for which the regulator is set, the turbine will be loaded up to full overload capacity. Although this does not represent a serious situation, it should be anticipated.

Means are provided on the governor gear to prevent loading above any arbitrary figure, below and up to full overload. This is accomplished by the load limiting device (12).

Equally possible is a situation where the low pressure header pressure rises above the upper pressure limit of the pressure regulator. This means that the top turbine will be unloaded. As long as the generator is tied in with the system, the speed will stay constant, and the synchronous generator will become a synchronous motor. This condition, having no ill effects on the generator, may become highly undesirable for the turbine if prolonged.

On an extremely high pressure top turbine the exhaust pressure may be from 200 to 400 lb per sq in. Steam under this pressure represents a medium of considerable density. In this medium the turbine spindle is revolved at normal speed, and because the admission valves are closed no steam will circulate.

It is obvious that it will not require much time before the steam yet contained in the cylinder will reach a temperature that will seriously endanger the blades. This is a condition which must not occur. In order to prevent serious overheating a certain amount of high pressure steam is permitted to flow at all times when the turbine is in operation — even when the admission valves and the throttle valve are closed. This steam, of an amount less than that required to keep the unit rolling at full speed but sufficient to keep the blading from overheating, is by-passed around the throttle valve and one of the inlet valves.

Another emergency condition arises if the generator of the superposed turbine should suddenly lose its load. If the turbine was operating under speed control when the electric load is lost, a certain overspeed would be reached. Its value would depend on the load carried and the ability of the valve gear mechanism to shut off the supply of steam.

If the top turbine was under pressure control at the time the load is lost, the speed governor would immediately tend to shut the valves. But due to the fact that the load probably would be thrown onto low pressure generators, the pressure on the low pressure header would decrease. This decrease in pressure would actuate the pressure regulator and tend to increase the steam flow to the top turbine, while at the same time the speed would increase and the speed governor would tend to shut the inlet valves. The fact that the speed governor and the pressure regulator would partly counteract each other means the closing of the admission valves would be retarded to a certain extent. Under all conditions, however, the tripping speed should not be reached.

• Protective devices

There are a number of protective devices by means of which greater safety in the operation of the high pressure boilers and the top turbine can be assured. The question of whether this or that device should be applied depends entirely on the purpose of the top turbine and the characteristics of the particular installation.

The by-pass around the throttle and inlet valves of the top turbine is important in any case and can be considered a necessity.

An atmospheric exhaust between the top turbine exhaust and the check valve is a desirable feature, if only for the purpose of keeping leakage back through the check valve away from the turbine during shut-down periods.

On one installation a by-pass line with desuperheater station was installed to make it possible to maintain the supply of steam from the high pressure boiler to the low pressure header, in case the superposed turbine should be out or should suddenly go out of operation.

The superposed turbine has, besides these special protective devices, all the other standard protective devices for condensing turbines, such as excess speed governor (30), solenoid trip (31), and a pressure regulator which automatically starts the auxiliary oil pump in case a main oil pump should fail.

The large top turbine is usually equipped with a turning gear, which keeps the turbine spindle revolving at low speed during shut-down periods. A separate motor-driven oil pump is usually provided to furnish the lubricating oil when the turning gear is in operation. Protection of the bearings against loss of oil is secured by an oil pressure actuated switch which shuts down the turning gear motor when the oil pressure drops below a certain limit.

The above explanation indicates that the problems inherent in the installation of superposed turbines have been recognized and carefully considered. Therefore, a consideration of the problems involved in each specific installation, combined with an appreciation of the solutions suggested above, will lead to safer and more satisfactory utilization of this relatively new addition to power station equipment.

MAKING SPARKS FROM ARCS

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The electric arc is a very useful device in an electric furnace, and engineers designing electric furnaces are looking for hotter and more destructive arcs. On the other hand, because an arc is destructive there are many engineers interested in suppressing arcs to such an extent that their destructive effect is negligible. In fact, this group of engineers would eliminate arcs entirely, but with the present knowledge of circuit interruption arcs cannot be entirely avoided. General circuit applications require physical making or breaking of the circuit, necessitating undesirable arcing.

The past few years have seen a great increase in available knowledge relating to means for reducing or suppressing arcs, transforming large arcs into little ones. Scientific arc control studies have shown how to reduce the arc energy of circuit interruption. Big arcs are characterized by the dissipation of a considerable amount of arc energy; sparks have very little arc energy. Arc energy is the factor to be controlled in order to reduce the destructive characteristics of an arc. High arc energy results in rapid deterioration of parts and burning of contacts, whereas low arc energy causes but slight contact burning and permits circuit interrupting devices to operate with greater effectiveness.

Arc energy is a product of:

Voltage drop across the contacts, e

Current in the arc, I

Power factor, cos θ

Duration of the arc, t

Arc energy is expressed in kilowatt seconds as follows:

$$\text{Arc energy} = e\ I \cos \theta t$$

A comparison of an older type of contactor motor starter with the confined-arc interrupter now in use on some modern motor starters indicates how much more efficient the modern devices actually are. Figure 1 shows a modern confined-arc interrupter. Figure 2a illustrates the action of the older, conventional type of contactor starter in which the natural magnetic blowout effect in the loop circuit of the contacts distends the arc so far that it just blows itself apart and interrupts the circuit. That is, it inserts so much resistance through the increasing length of the arc that the current is diminished, and, finally, when the arc breaks, the contacts are open far enough so that the recovery potential cannot restrike the arc.

When the arc is distended over a considerable distance, the voltage drop across the arc is high. Since, as explained above, the voltage drop across the arc is one of the main factors in determining the value of arc energy, it can be concluded that if the voltage drop is high the arc energy will be high; and contact destruction will be proportionately high. Contrasted to the above is the action of the modern interrupting device with its enclosed arc, as shown in Fig. 3a. The voltage drop across the arc in an interrupter of this type is very small compared to that across the contactor type previously described. This low voltage is an important contributing factor to low arc energy in the interrupter equipped with this type of device.

These facts are deduced from the accompanying oscillograms. Figure 2b is that of an oscillogram showing the interruption by the old style contactor of a stalled rotor motor circuit at 440 volts. The arc duration was four half cycles. The voltage drop was large, as can be seen on the oscillogram. The same fact is evidenced by the diminishing current values for each successive half cycle. The amount

Fig. 1 — Interrupter Unit Complete with Stationary Contact and Terminal.

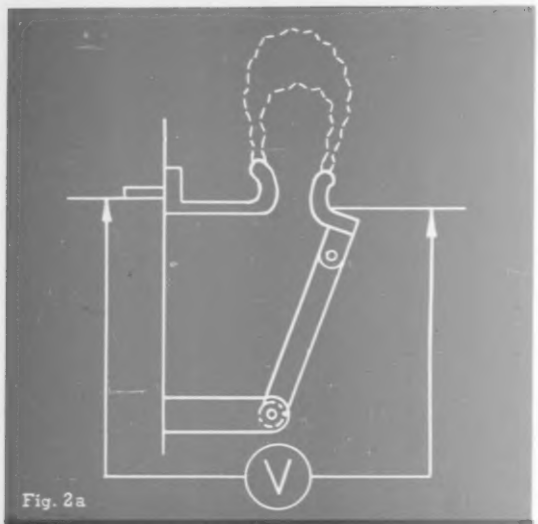

Fig. 2a

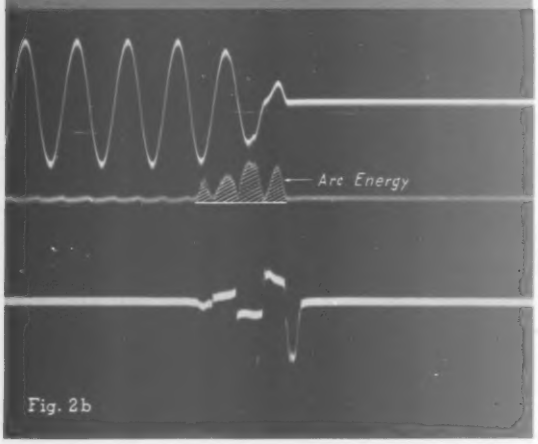

Fig. 2b

of arc energy is indicated by the shaded area of the arc energy curve.

Figure 3b was taken on the same motor circuit under identical conditions as those of Fig. 2b except that here a modern enclosed confined-arc motor starter was used instead of the old type of contactor, to close and open the circuit. The arc duration is seen to be less than one-fourth that of the contactor. Inspection of the two oscillograms shows the voltage drop across the confined-arc interrupter contacts to be much less than that across the old type of contactor; moreover, a direct comparison of the arc energy areas shown in the two oscillograms reveals how very much more efficient the confined-arc interrupter motor starter actually is.

The confined-arc interrupter employs no magnetic blowout or arc chute, nor does it have a long stroke; it confines the arc in an enclosing chamber. The small space in which the arc is drawn is surrounded by the cooling walls of the confining tube. This confining enclosure reduces or suppresses the arc to a mere spark so that even on severe service the arc interrupting time seldom exceeds 0.0083 seconds. This reduction in time is highly desirable, because, as noted above, time is a factor in determining the value of arc energy.

It is to be noted that even on the most severe stalled rotor motor current interrupting tests the arc is not drawn outside of the enclosing tube.

The high efficiency of the confined-arc interrupter equipped motor starter means that contact burning is reduced to a minimum. Similarly, the production of gas is reduced to a minimum. This means that this type of motor starter can be mounted in non-ventilated cases, such as dust-tight, water-tight, and explosion-proof enclosures, without fear of excessive gas accumulation due to repeated and frequent operations such as are frequently encountered in inching and plugging service.

The ability of the confined-arc interrupter to make mere sparks out of arcs indicates the future trend of motor starter design. One can therefore look forward to motor starters which are small in size but extremely effective in performance.

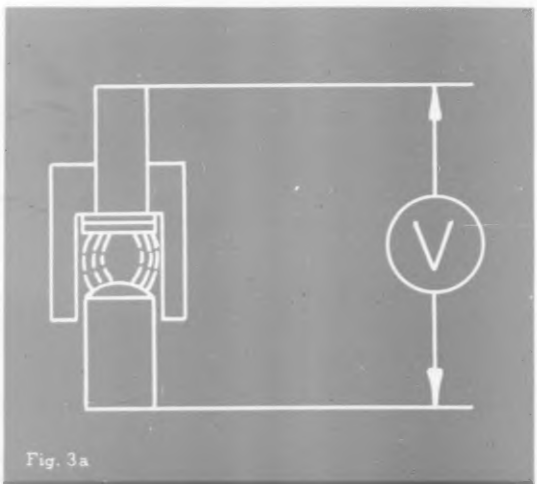

Fig. 3a

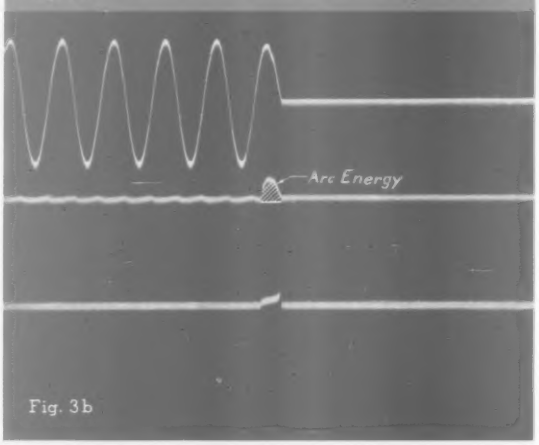

Fig. 3b

STEP REGULATORS FOR DELTA-STAR OPERATION

• F. W. Bush
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MFG. CO.

The step type feeder voltage regulator which has recently established itself as a major factor in the field of voltage regulating equipment is essentially a transformer arranged for tap changing under load. Regulators of this type are available in both single-phase and three-phase units. The three-phase regulators are usually star-connected; and since this connection may be used on both grounded and ungrounded systems, the delta connection is usually unnecessary. It is sometimes convenient, however, to have the regulator suitable for both the delta and star voltages so that it may be used first on the delta voltage and later at the higher star voltage. For instance, there are numerous 2400 volt delta-connected systems in present use which will eventually be converted into 4160 volt star-connected systems; and it is, therefore, quite an advantage to have a regulator which may be operated at either of these two voltages.

In general the most economical way of obtaining this double voltage rating is to have the regulator suitable for the higher of the two voltages and operate it at reduced voltage on the lower voltage system. With this method the auxiliary control windings may be supplied with taps so that suitable voltage is available for operating the control instruments at both the high and low primary voltages. This feature can be very easily built into the regulator, and the increase in cost is nominal. By the use of this method the regulator is capable of carrying the same current and giving the same per cent regulation on either circuit.

A second method of accomplishing this same result is to design the regulator so that it can be connected in either delta or star, as shown in Fig. 1. It must be remembered that since the series winding is connected in series with the line in both cases, the current rating of the regulator is the same for both the delta and star connections. The range of regulation, however, is increased 50 per cent by the use of the delta connection. It is also to be noted that the delta connection produces a phase

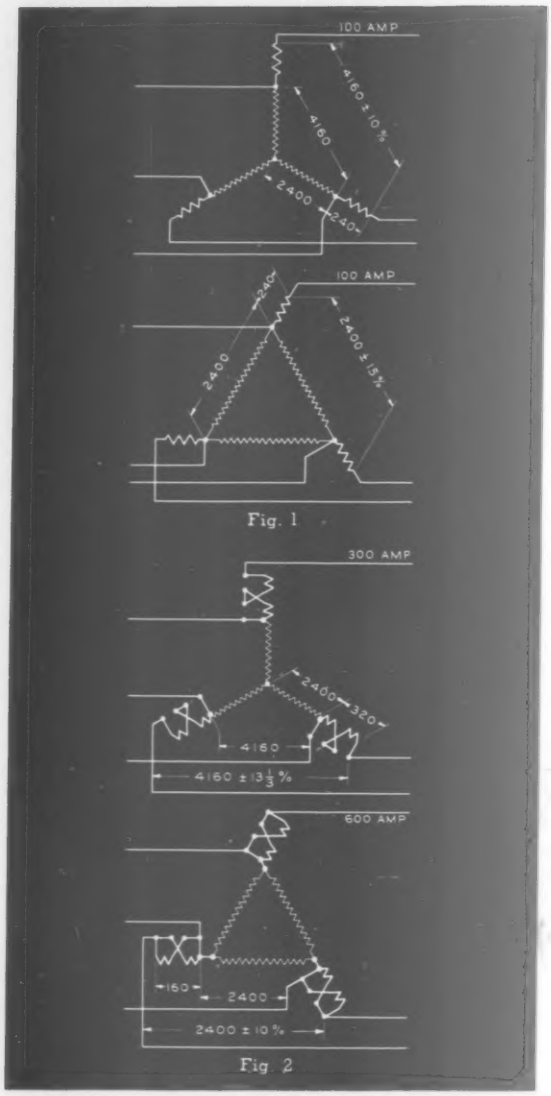

Fig. 1

Fig. 2

shift in the output voltage, which may be objectionable on some circuits, and this phase shift is also responsible for a loss in kva. For example, if the star-connected rating is 4160 volts with plus and minus 10 per cent regulation, 100 amperes, the delta-connected rating would be 2400 volts plus and minus 15 per cent regulation, 100 amperes. The kva rating using the star connection is

$$4160 \times \sqrt{3} \times .1 \times 100 = 72 \text{ kva}$$

and with the delta connection it would be

$$2400 \times \sqrt{3} \times .15 \times 100 = 62.3 \text{ kva}$$

The complications encountered in arranging for the delta-star connection, of course, add considerably to the cost of the regulator; and since the current rating is not increased by the delta connections, this method is not generally preferred.

A third solution to the problem is possible if the current rating of the regulator is high enough to require the use of a series transformer. Then the series winding of the series transformer can be designed for series-parallel connection, as shown in Fig. 2. In this way ratings more comparable with typical circuit ratings may be obtained. For example, the series winding may be wound for 6⅔ per cent voltage on the parallel connection and 13⅓ per cent voltage on the series connection. Using the parallel connection with the delta-connected primary, overall regulation of plus and minus 10 per cent can be obtained. The series connection can then be used with the star-connected primary to give plus and minus 13⅓ per cent regulation. The current rating of the delta connection in this case will be twice that of the star connection.

Assuming a star-connected rating of 4160 volts plus and minus 13⅓ per cent, 300 amp, then the delta rating would be 2400 volts plus and minus 10 per cent, 600 amp. The kva rating for the star connection is

$$4160 \times \sqrt{3} \times .133 \times 300 = 288 \text{ kva}$$

while the delta-connected kva rating would be

$$2400 \times \sqrt{3} \times .10 \times 600 = 250 \text{ kva}$$

It is interesting to note that there is the same loss in kva using this method as with the preceding example; but this latter case permits higher current operation on the delta connection, and the regulation ranges for the two connections are more nearly equal. This method also produces the same phase shift in the output voltage when using the delta connection and is in general an even more expensive arrangement, due to the delta-star and series-parallel connections.

Because of the inherent disadvantages of connecting step type feeder voltage regulators in delta, most of these units are star-connected even though they are for use on delta-connected systems.

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Photograph Titles

Cover 1
D-C generator armature, 3000 kw, 600 volts, 360 rpm.

Page 4
Assembling anode plate on a mercury arc rectifier. The men are dressed in spotless white to maintain the scrupulous cleanliness necessary to prevent any kind of foreign matter coming in contact with the mechanism.

Page 5
Mercury arc rectifier for 50,000 volts, 2000 kw.

Page 10
Three-Winding Transformers: HV 20,000 kva, 132,000 volts; LV 26,667 kva, 34,500 volts; TV 20,000 kva, 13,200 volts with forced air cooling.

Page 14
Fig. 15 — Phase angle side of 10,400 kva regulating transformers; three phase, 2400 volts, 250 amp.

Page 15
Fig. 16 — In-phase regulating side of transformer on page 14.

Pages 18 and 19
Part of a shipment of 30 mercury arc rectifiers for use in a large electrolytic metal refining plant; rating: 2750 kw, 600 volts.

Page 21
Two 1500 kw, 500 rpm, synchronous motor generator sets for use in a large steel mill.

Page 30
Interrupter unit installed on an oil circuit breaker, 4000 amp, 1,000,000 kva interrupting capacity.

Page 33
Step voltage regulators, 1200 kva, three phase, 60 cycles, for 13,200 volt circuit.

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